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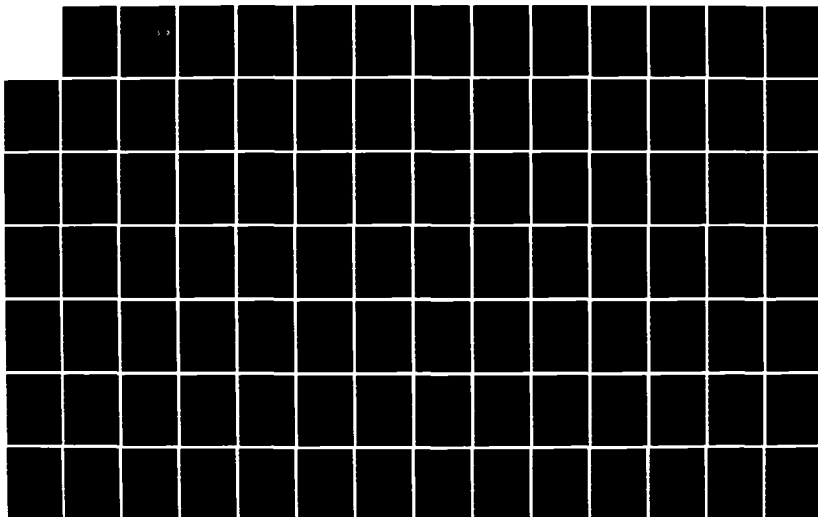
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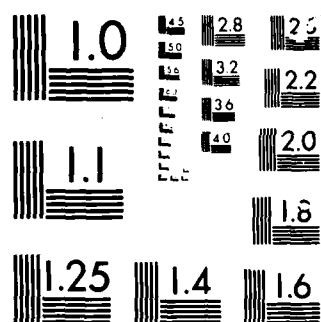
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AN ANALYSIS OF THE DEFENSE
SPACECRAFT MARKET

THESIS

Brad S. Bigelow
Captain, USAF

AFIT/GSO/ENS/85D-2

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AFIT/GSO/ENS/85D-2

AN ANALYSIS OF THE DEFENSE
SPACECRAFT MARKET

THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
Air University
In Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Space Operations

Brad S. Bigelow, B.A., B.S.
Captain, USAF

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This study examines the defense spacecraft market in the context of the classical industrial organization paradigm. It takes as the basis for its evaluation of the market the concept of effective competition, using the criteria proposed by Stephen Sosnick in his article, "Toward a Concrete Concept of Effective Competition."

The investigation begins by briefly describing the origin and evolution of the military space program. It then addresses the structure of the market, outlining the composition and concentration of the industry, the nature of the product, the extent of demand, and the conditions of supply. It discusses the particular structural features of the Department of Defense market.

It shows how the conduct of the market is predominantly influenced by the DOD acquisition process for space systems. The examination of market performance focuses on internal and allocative efficiency, revealing a dramatic decline in productivity since the mid-1960s, due in large part to the increase in the unit cost of materials.

It concludes by highlighting the links between the structure, conduct, and performance. It shows how deviations for effective competition in the market result from these interactions, and recommends areas for further research.

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Abstract

This study examines the defense spacecraft market in the context of the classical industrial organization paradigm. It takes as its basis for evaluating the performance of the market the concept of effective competition, using the criteria proposed by Stephen Sosnick in his article, "Toward a Concrete Concept of Effective Competition."

The investigation begins with a brief description of the origins and evolution of the military space program. It then describes the structure of the market--the composition and concentration of the industry, the nature of the product and the extent of demand, and the conditions of supply.

The discussion of conduct in the market focuses on the acquisition process for Department of Defense space systems and the responses of industry members to this process. The discussion of performance concentrates on the issues of internal and allocative efficiency, and reveals a marked decline in productivity since the mid-1960s.

The study concludes by highlighting the links between critical dimensions of structure, conduct, and performance. It shows how deviations from effective competition in this market result from these interactions, and recommends further research into several aspects of the market.

AN ANALYSIS OF THE DEFENSE SPACECRAFT MARKET

I. Introduction

This chapter establishes the need and framework for this thesis. It briefly discusses the criticisms leveled at the defense industry, then analyzes one weakness in the economic logic used to support such criticisms--the definition of what constitutes an "industry." It shows why studies of the individual industries--in this case, of the spacecraft industry--are needed to assess the competitiveness of the defense market. The basic question this thesis attempts to answer is stated, along with the subsidiary questions addressed in the research. Next, the approach and methodology of the research are described, including the limitations which must be placed on the findings of this study. Finally, an outline of the remainder of the thesis is presented.

Background

The defense industry has long been the target of criticism that finds it insufficiently competitive for the good of the public. Its critics cite enormous cost overruns, astronomical profits, inefficient producers, and unacceptable goods (2:280). Many of these critics hold up this evidence against the economic model of perfect competition and find it wanting. One investigation stated that "the absence of competition removes normal safeguards against large profits

and weakens the Government's negotiating position" (147:136). Gansler, in his book on the defense industry, lists other examples of the market failures and imperfections they identify: "prices rise with demand"; "extensive barriers to entry and exit"; "very few, large suppliers of a given item"; and "only 8% of dollars awarded on price competition" (68:30-31). Based on these and other discrepancies, they conclude the industry is not competitive. Whether their conclusions are true or not, their arguments are substantially weakened by flaws in their economic reasoning.

Their definition of an industry--defense--is less than useful for the purpose of economic analysis. It is a layman's term, misused in this context. "The notion of subgroups of firms, termed 'industries,' is a part of everyday life," writes Douglas Needham. "When one attempts to define 'an industry,' however, matters are not so simple" (106:78). Economic theory indicates that an effective definition of an industry should account for substitution of production and consumption.

On the production side, firms can be considered members of the same industry if they employ essentially the same skill and equipment, and are capable of converting to each other's product line in the short run. On the demand side, firms should offer goods and services that are close substitutes for each other in the eyes of the buyers. This substitutability is often measured by the cross-elasticity of demand between goods, the degree to which the sales of one product are

affected by the change in price of another. It is sometimes difficult to measure cross-elasticity; in these cases, another measure, that of "the ideal collusive group," is used. On this basis, the members of an industry are those firms that an individual firm would choose as members of its cartel if it were legally possible to collude in setting prices (118:44). Without commonality in production and consumption, an industry cannot be defined in an economically meaningful way.

By this principle, the defense industry is not effectively defined. The firms in the industry provide goods ranging from bullets to aircraft carriers, services from running mess halls to conducting advanced laser research. And their facilities can be as simple as a small repair shop or as sophisticated as a research, development, and test laboratory. Although they share a common customer--the Department of Defense--there are numerous, distinct procurement organizations within the Department, each with special needs, policies, and practices.

To compound the problem of definition, many analysts rely on simplistic economic models to evaluate their evidence. They understand the workings of the models of pure competition and monopoly. Pure competition requires many firms, producing a homogeneous product, with price set by demand, and zero economic profits. Anything less than these tends toward the monopoly model, and the implied social evils therein.

Economists have long realized that pure competition probably does not exist in this world, never has existed, and

never can (148:3). Instead, firms work within constraints of supply, production, and demand that may inherently force them away from the competitive model and toward monopoly.

The concept of effective competition attempts to bridge this gap between theory and reality. First explicitly outlined by J. M. Clark, who first called it "workable competition" (35:241), it was a response to the use--or, more accurately, the abuse--of the pure competition model to dictate public policy:

A more troublesome consequence of the model consists of the normative conclusions that are, rightly or wrongly, drawn from it. As a standard of so-called "perfection," it is one-legged, focusing on the essentially static objectives of cost-price equilibrium, to the neglect of the dynamic objectives of progress. This one-legged standard is frequently treated, without warrant, as an ideal. And because it is unattainable, all actual or possible conditions are, by comparison, judged inferior . . . or monopolistic [10:451].

Clark proposed an alternative way to judge the performance of markets, one that accounted for the realities of supply, production, and demand. If pure competition is not possible, then effective competition is "performance that satisfactorily enhances the aggregate economic welfare without gross and important discrepancies from the ideal performance of the market" (19:14). This argument holds that the best performance possible in a market is not, practically, pure competition, but performance such that any feasible change in its structure or conduct would in some decrease in social welfare. It is similar to the concept of sub-optimization in linear programming, which says, in effect, "Do the best with what you have"--which is not necessarily the best possible

given unlimited information, resources, and time.

Unfortunately, just what is best cannot be precisely determined in most cases. The criteria for determining pure competition are simple. The criteria for determining if an industry is effectively competitive are more numerous, and often subjective. They consist of various structural, conduct, and performance norms (128:389-391). In many cases, it is difficult to avoid value judgments; in others, it is hard to tell if a condition has been met or not (118:43). Yet, in the absence of more objective yardsticks of industry performance, effective competition remains a useful approach, and is still offered as a tool in most texts on industrial organization (19; 76; 87; 91; 118; 149).

This may be because effective competition embodies a paradigm of the process of industrial analysis itself. As Scherer outlines in his text, industrial analysis examines the basic conditions and structure of industries, their conduct, and their economic performance (118:3-5). The structure of an industry is the organizational characteristics that significantly influence the nature of pricing and competition in an industry (19:7). Its conduct is the set of practices that buyers and sellers follow in responding to the dynamics of the market. Performance is the result of the firms' efforts--their outputs, prices, costs, technological innovations, efficiencies, and product qualities. These elements do not exist independently; there are feedback effects among them, and a complete industry analysis must

consider these interactions (118:4-5).

Clearly, to evaluate the criticisms of the defense industry, it is necessary to examine the individual defense industries and identify common instances toward or away from effective competition. Each discrepancy must be measured against the available policy alternatives, and the net benefit or loss expected from each change estimated. Only then can public policy be accurate and effective.

Among the more critical defense industries is the spacecraft manufacturing industry. The Department of Defense relies on satellites for essential communications, navigation, meteorological, reconnaissance, and surveillance support of its forces. Current military doctrine accepts space systems as integral parts of the defense posture across the spectrum of conflict. In the thirty years since the first military satellite program began, defense expenditures on space programs have increased from less than \$1 million in 1955 to almost \$13 billion in 1985 (8:52; 104:100-101). Similarly, the industry manufacturing satellites for the military has grown from a group of small engineering and research shops within aircraft companies to one of the top ten defense industries in terms of sales.

The United States has recently undertaken its most ambitious military space effort to date: the Strategic Defense Initiative (SDI), which aims to provide a defense against ballistic missile attack via a fleet of orbiting satellites. The research and development costs for SDI for

the next five years have been estimated at over \$26 billion (26:49). The US Air Force is also studying a piloted transatmospheric vehicle and a manned military space platform, both of which would represent significant extensions of the realm of military operations into space. In addition, a unified Space Command has been formed to carry out military operations in space.

But the ability of the United States to carry out these ambitious plans will depend not only on the military force involved, but on the industrial base supplying them as well. The aerospace firms are eagerly competing for SDI study contracts because the winners will gain the expertise to put them in good position for "a bigger piece of the action" when the SDI hardware contracts are awarded (25:120). But has the spacecraft industry adequately met the needs of defense in the past? Has it been able to produce technologically innovative spacecraft, without continual cost and schedule overruns? Has the industry earned reasonable, but not excessive, profit margins on defense contracts? Has the market encouraged efficient firms, firms that have supplied the customer's needs without important deficiencies? Are there areas which could be improved by changes in the DOD's procurement policies?

Specific Problem

These are questions of effective competition. Answering them requires study of the structure, conduct, and performance of the industry. Although many studies have investigated the nature of the aerospace industry, this term includes

manufacturers of avionics, jet engines, civilian and military aircraft, and civilian and military spacecraft. No study has examined the performance of those firms designing, developing, and producing satellites for military missions in the framework of a classical industry analysis. Given the importance of these systems--and, consequently, these firms--the desirability of such an industry analysis is clear.

Research Question

What do the relationships between the structure, conduct, and performance in the defense spacecraft market indicate about effective competition?

Subsidiary Questions. In the course of answering this question, this study will also address these questions:

1. How did the defense space program begin, and how did private firms become involved? How did the market grow, and what changes occurred among customers and firms during this period?
2. What constitutes the industry? Who are its members? What are its major markets?
3. What is the nature of the product and the conditions of demand, and supply? What is the character of its structure--concentration, the conditions of entry and exit, vertical integration, and government policies?
4. What are the salient features of the acquisition process for defense spacecraft, and how do they influence the conduct of sellers?
7. What are the effective measures of performance? What

is the record of efficiency in the industry? How does the industry compare with other defense industries in terms of productivity, costs, and profitability?

8. What are the criteria for effective competition? How does the evidence compare with these norms? Does the industry meet the standards, and if not, what is the extent and significance of the differences?

Methodology

The basic research design of this thesis is that of a case study. As laid out by Robert K. Yin, the five components of research design important for a case study are the study's questions, its propositions (if any), its unit of analysis, the logic linking the evidence with the propositions, and the criteria for interpreting the findings (151:29). For this thesis, these elements can be easily identified.

The question, stated above, could be further simplified to one that asks, "What is the nature of the industry?" For this reason, the study does not put forward any propositions, since it is what Yin terms an "exploration," an investigation into the characteristics of a subject rather than an attempt to test the validity of a hypothesis (151:30). In such cases, the research is directed to some purpose--in this case, to determine if there is a need for changes in public policy to improve the performance of the spacecraft industry. This industry is the unit of analysis. Since the industry can be broken into three sectors by the type of customer involved--the Department of Defense, the National Aeronautics and Space

Administration (NASA), or commercial space consortiums--this study focuses on the defense sector, and limits its treatment of the other sectors to the discussion of overall characteristics.

The logical framework for linking the evidence to the purpose of the study is the industrial organization paradigm developed by Mason and others, shown in Figure 1 (118:4-5). This model categorizes data according whether they describe an industry's basic conditions of supply and demand, its market structure, or its performance. These elements of the analysis are not discrete or independent--thus, the interactions among them is a subject that continually surfaces throughout the study.

The criteria are those structural, conduct, and performance norms identified by Sosnick and others as characteristic of an effectively competitive industry (129). These criteria are not all objective absolutes, but are guidelines within which subjective judgment are reached. Consequently, this thesis stands or falls on the validity of the evidence and the logic supporting these judgments.

Scope and Limitations

This study concentrates on the spacecraft industry as it has existed since 1978. During this period, the major military satellite contracts now in effect were awarded, and the outlook of the industry was significantly influenced by the realization of the Space Transportation System and the opening of space to commercialization ventures. In the

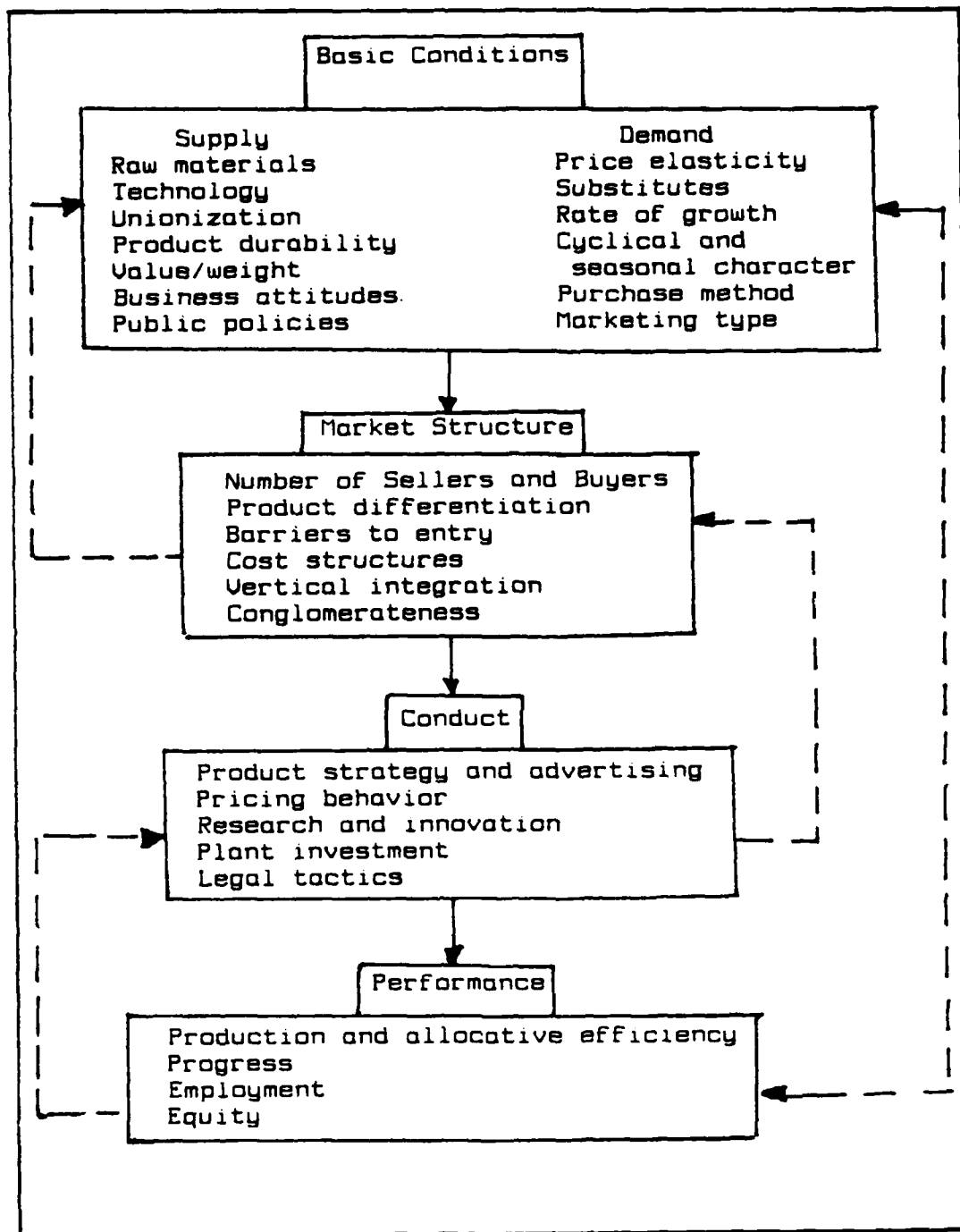


Figure 1. Industrial Organization Paradigm (118:4).

interest of security, it is limited to unclassified discussion of military space programs and missions. In addition, although international competition is growing rapidly in the commercial sector of the market, this study will not address the efforts of European and Japanese spacecraft manufacturers.

Like any other examination of a private industry from the outside, this study suffers from having to obtain most of its data second-hand. Much of the information about the companies in the industry is discerned "through a cloud of difficulties--variations in demand, products, product mixes, input prices, input qualities, long-lived commitments, cost accounting, obsolescence, distribution costs, etc." (128:398). It also suffers the implicit and explicit shortcomings and biases of a one-person effort.

Definition of Terms

Since several terms are used frequently throughout this thesis, it is worthwhile to take a moment to clearly define their meanings. "Spacecraft" and "space vehicle" refer to any man-made vehicle launched from the Earth to operate in space, and includes artificial satellites, upper stage propulsion units, planetary and interplanetary probes, and manned space vehicles. "Industry" refers to the commercial firms engaged in the business of producing and marketing a common set of products--in this case, spacecraft. The "missiles and space industry" equates to the Standard Industrial Classification (SIC) 3761, Guided Missiles and Space Vehicles, while the "spacecraft industry" equates to SIC 37612, Complete Space

Vehicles. "Market" refers to both the members of the industry and its major customers.

Outline

Chapter 2: Effective Competition. This chapter presents a discussion of the origin and development of the concept of effective competition and the major approaches to it. It reviews the various criteria proposed by which to determine its extent in an industry, and identifies the particular approach used in this study.

Chapter 3: Development and Structure of the Industry. The origins of the military space program are briefly discussed, along with the entry of firms into the market, and the growth of the market through the present. The process of developing, designing, and building a spacecraft is outlined to provide an understanding of the conditions of production. The appropriate structural indexes are examined, along with the basic conditions of the industry--the nature of spacecraft as a product, and the forces of supply and demand. Key features of structure, including concentration, strategic groups, the conditions of entry and exit, vertical integration, and networking among industry members are also discussed.

Chapter 4: Conduct and Performance. This chapter opens with a review of the major systems acquisition process and the types of contracts involved. It looks at how the distinctive character of this process has influenced the response of sellers, and how this response differs among strategic groups.

The discussion of performance focuses on the internal and allocative efficiency of the industry.

Chapter 5: Interpreting the Evidence. Here, the salient facts about the industry are matched against the effective competition criteria, and a judgment is reached. Some interpretation of what the results mean for public policies is attempted, along with suggestions for further studies.

II. Effective Competition

This chapter reviews the literature on effective competition as a basis for evaluating an industry. It briefly discusses the origins of the concept as an approach to bridging the gap between economic theory and public policy. It outlines the concept as it was first explicitly stated by J. M. Clark, then reviews the various approaches to the concept and addresses the criticisms of the concept. Finally, it lists some of the many different criteria proposed for determining if an industry was effectively competitive, and identifies the approach used in this study.

Origins of the Concept

The idea of effective competition has its roots in the discussions of economists in the 1920s and '30s over the application of economic theory to public policy. Economists, beginning with Adam Smith and his theory of the free market society, have long held up pure competition as the ideal for the public good. At the same time, few would deny that the criteria for pure competition--a very high number of sellers, offering a homogeneous good at a price based strictly on demand, with no seller large enough to influence the behavior of the market--are too stringent for any real industry to meet them. When economists began to enter the realm of public policy-making in the first decades of this century, they saw a gap between what economic theory took as the ideal and what society, through its antitrust laws, took as its goal.

Beginning in the early thirties, several economists attempted to extend the theoretical framework into the middle ground between monopoly and pure competition (91:11-13; 95:197-8). Joan Robinson offered "imperfect competition," a variation of perfect (pure) competition that redefined the demand curve to account for interdependence among firms. E. H. Chamberlin developed the theory of "monopolistic competition," to accomodate forces like brand competition and geographic location in a competitive model. Joseph Schumpeter conceived a radically different approach to competition, one based on differences in technology between producers (91:39-43).

At the same time as these theories were being developed, the new field of industrial organization provided empirical data on the intermediate territory, through industry studies and antitrust investigations. These studies usually followed the model of basic industrial relationships developed by Edward S. Mason, who divided market characteristics among three categories: structure, performance, and conduct (118:4). Industrial economists were eager to find a framework that would help them to evaluate their data.

In 1937, Mason highlighted these differences in his article, "Monopoly in Law and Economics" (139:243). Mason described how the term "monopoly" was being used in legal practice as a standard for evaluating business practices. The use of contracts to restrain trade and other predatory business practices were considered attempts to monopolize, violations of the Sherman Act. To economists, on the other hand,

"monopoly" referred to a clearly understood model of the market, characterized by monopolist's ability to set his own price, to control the market to his choosing.

This distinction between the legal and economic views of monopoly extended to their respective views on competition as well. "The antithesis of the legal conception of monopoly is free competition. . . . [T]he antithesis of the economic conception of monopoly is not free but pure competition [emphasis in the original]" (139:243). Those who tried to use the theory of pure competition in making public policy confronted the fact that nearly all market situations contain elements of both monopoly and competition. According to Mason, "the formulation of public policy requires a distinction between situations and practices which are in the public interest and those that are not" (139:243).

The Concept of Workable Competition

Three years after Mason's article, J. M. Clark proposed an analytical framework for examining market situations and business practices as they exist in the real world, incorporating economic ideas and theories, but aimed at providing guidelines for public action (110:186). In simplest terms, Clark's "workable competition," which term he later changed to "effective competition," is the best market arrangement possible within the constraints of a free enterprise system. He supported his argument that pure competition was inadequate as a guide for public policy by citing the theory of the second best, which showed that in the

absence of a single characteristic of pure competition in an industry, forcing the remaining characteristics to follow the model did not necessarily result in the maximum public welfare possible. "If there are, for example, five conditions, all of which are essential to perfect competition, and the first is lacking in a given case, then it no longer follows that we are necessarily better off for the presence of any one of the other four" (36:242). Consequently, argued Clark, attempting to legislate all industries toward pure competition might result in more harm than good.

Clark began by identifying ten factors which help to characterize competition in an industry (36:243):

1. The standardized or unstandardized character of the product.
2. The number and size-distribution of producers.
3. The general method of price-making.
4. The general method of selling.
5. The character and means of market information.
6. The geographical distribution of production and consumption.
7. The degree of current control of output.
8. Variation of cost with varying size of plant or enterprise.
9. Variation of cost with short-run fluctuations of output.
10. Flexibility of productive capacity.

He then described how, despite deviations from pure competition in an industry, the forces of potential competition and substitution can mitigate the seriousness of these defects (36:246-8). He emphasized the time dimension of the supply and demand curves, which is missing from the classical market model: "[I]n actual elasticities of demand a crucial element is the time required for a given change of price to bring about a given effect on volume of sales"

(36:247). When the dynamic aspect of competition is borne in mind, Clark explained, the long-run effects of one firm's high prices would be a much larger loss of sales than would occur in the short run (36:248). He also proposed that when differences in size exist among competitors, strong product differentiation creates uncertainty that inhibits high prices (36:249).

In this article, Clark did not propose criteria by which to judge the workability of competition in an industry, but only argued that deviations from pure competition could work synergistically to achieve the same social benefits expected from pure competition. However, his concept of workable competition, which could be judged from the interaction of the specific conditions in an industry, was eagerly taken up by economists, particularly those interested in industrial organization. Over the next two decades, at least eighteen different views of what constituted workable competition and the criteria by which it could be measured were presented (128:380).

Approaches to the Concept

The concept of workable or effective competition was one of the hottest topics in economics throughout the forties and fifties. Its defenders saw it as the most effective means for translating economics into public policy on the operation of markets, but differed over the criteria to use. Its critics felt the concept failed as a tool for positive economics because it supplied "no formula which can substitute for

judgment" (109:188). The sixties saw its fullest elaboration, as well as its demise as an operational tool in the eyes of many economists.

Stephen H. Sosnick comprehensively reviewed the development of the concept through the late sixties in his articles, "A Critique of Concepts of Workable Competition" and "Toward a Concrete Concept of Workable Competition" (128; 129). Two points are generally agreed upon: first, that perfect competition "is not a reliable basis for normative appraisal of actual markets"; second, that it is necessary to have explicit criteria of workable competition (128:380). The focus of most of these authors--and the point of most disagreement--was the particular criteria required. The various criteria proposed fall into three categories--structure, conduct, and performance.

The writers differed on criteria in two ways (128:381). Some disagreed on the basis of effective competition, and hence, the categories from which to draw their criteria. Edwards, for example, proposed to judge industries strictly on structural characteristics; Markham, on the other hand, favored a purely performance-oriented standard (57:9-10; 94:349). Other writers recommended different combinations of structural, conduct, or performance criteria. The other point of disagreement was the specific criteria chosen within the respective categories. Three writers, for example, held that, as conduct norms, there should be no misleading advertisement, while six others held that there should be no unfair or

predatory practices (128:391).

The different views on specific criteria will be discussed later in this chapter. The range of views on the essential nature of effective competition--the various combinations of categories--will be outlined by reviewing the views of the main proponent of each position.

The primarily structural approach to effective competition was advocated by Corwin Edwards (57:9-10). He held market organization to be the key to maintaining competition, and identified seven structural characteristics of competitive markets. Competition, in his view, "consists in access by buyers and sellers to a substantial number of alternatives and in their ability to reject those which are relatively unsatisfactory" (57:9). As Low and Sosnick have shown, Edwards' approach is unrealistic (91:47; 129:830). His criterion of ease of entry, for example, is infeasible in some markets; another, that there be an appreciable number of sources of supply, is not attainable in many situations if "appreciable" means more than one.

The problem with a purely structural approach is that it places too much reliance on certain market forces--countervailing power, potential entry, avoidance of antitrust, and preference for long-term over short-term profits--to maintain an effective equilibrium. Simply meeting structural norms is not a sufficient condition for optimal performance of the market. Moreover, if performance data are available, there is no reason to restrict one's analysis to structure.

At the other extreme to Edwards is the approach suggested by Jesse Markham, which is essentially a test of market performance (94). Using the rayon industry as an example, he listed its significant characteristics, including its manufacturing processes, price leadership and stability, tariff protection, and rate of expansion and growth (94:351-354). He used the rayon industry because he considered there was no a priori basis for a judgment, since it both failed to meet the conditions for pure competition and had not been the subject of antitrust action for over a decade at the time of the article (94:350-351). He then described how any attempt through public policy to change the industry to bring it closer to the pure competition model would result in greater social loss than social gain (94:354-358). Hence, he concluded, the rayon industry was effectively competitive.

In fact, Markham's test is performance-oriented only on the surface, and masks the analysis of the "relevant variables" of the rayon industry that precedes it (128:828-829). Indeed, Markham prefaces his discussion of the test by saying, "In any case, the workable competitiveness of a particular industry is open to debate only after the structural characteristics of its market and the dynamic forces that have shaped them have been appraised" (94:358).

The practical problem with a purely performance-oriented approach is that, in many cases, it is only instances of extremely good or bad performance that can be detected (128:397). Evidence on costs and profits must usually be seen

through a screen of accounting methods, production decisions, and management policies. As Sosnick puts it, "[O]nly certain extraordinary profit or loss rates could fail to be rationalized by the many accounting problems and the justifications of risk-bearing, innovation, cost performance, and resource reallocation" (128:398). Beyond this practical problem is the conceptual problem of focusing only on the end results of a market without regard to the means by which it was achieved.

Most writers suggest a combination of structural, conduct, and performance norms (128:389-391). They acknowledge the interrelationships between these areas as contributing factors in the degree of competitiveness in an industry. Failure to examine and identify all types of deficiencies may result in a conclusion that a particular market is effectively competitive even though there may exist serious deficiencies in other variables (129:836). Comprehensiveness of criteria is a key to the usefulness of the concept:

. . . if the concept of workable competition is to provide a reliable criterion for judging whether a market situation is socially satisfactory, it must ignore no dimensions of normative significance and appraise simultaneously those which are interdependent [128:399].

At the same time, performance is generally considered to be "of ultimate importance" (128:381). Indeed, Bain defines the "primary meaning" of effective competition as effective performance (19:16). The flip-side of the disadvantage of performance tests as described above--that only extreme cases

can be clearly identified--is that performance tests most clearly identify the extreme cases of bad or good situations (19:16; 128:392). At the same time, performance norms summarize questions of value judgments implicit in the operative concept of effective competition (128:392).

Criticisms of the Concept

Such value judgments are the focus of most criticism of effective competition. The claim that effective competition provides a more useful guide for public policy than pure competition is undermined, say critics, by the fact that, in the end, it offers no objective substitute for judgment (109:188). Indeed, most proponents do not state the social welfare values underlying their concepts of workability.

Bain is one of the few writers to explicitly refer his definition to the operation of the economy as a whole (19:13). He identifies the principle measures of social welfare represented by aggregate industrial performance: employment, production efficiency, stability, progress, composition of aggregate output, and the distribution of income. He then suggests that for each dimension, "it is possible to establish certain standards or norms of what would be the most satisfactory performance from the standpoint of the total populace" (19:13).

Stigler, however, rejects the notion that such standards can be established with any certainty:

The doctrine of workable competition has a purpose which is uncommon in the history of economics: it purports to be a rule of applied ethics which will tell us in each case how social policy should proceed [138:505].

The problem with prescribing a fixed set of norms, says Stigler, is that this approach fails "to recognize that the society's standards of acceptable performance change over time, sometimes fairly rapidly" (138:505). Since its proponents reduce the concept to a list of criteria without identifying their underlying assumptions about social welfare, he argues, "it attracts all the protagonists, who seek to bend it to their purposes" (138:505). He concludes, consequently, that the concept "is unlikely to assist in the study of the subject to which it pertains" (138:505).

Pegrum echoes Stigler's arguments, reiterating that effective competition fails because it cannot offer a precise gauge by which to tell when industry practices have reached a point where they must be curbed (109:188). He suggests that, at best, the concept is redundant to the traditional models of competition and monopoly. The formal models alone "provide us with the conceptual apparatus, nomenclature, and criteria by which we define economic efficiency and evaluate the significance of the departures therefrom" (109:189).

Hay and Morris argue that the concept "ignores the second-best theory" (80:559). Pareto analysis shows that in the absence of all optimal conditions, affecting a change to the optimal in a single condition does not necessarily improve the overall situation, and may in fact worsen it. Consequently, unless competition per se is good, effective competition can only work through "an all-or-nothing Faretian policy package" (80:559). Although this is agreeable in theory, in operation

it requires an extensive apparatus to identify all types of structure, conduct, and performance deviating from the optimal, define the socially acceptable standards for these areas, and investigate all possible legal and administrative sanctions to determine the best policy package. "Sadly," they conclude, "the state of economic analysis . . . is simply not adequate for so complicated a task" (80:560). Scherer argues that this analysis problem just condemns the second-best theory as a guideline for public policy, and suggests that the practical approach is the "third best"--to choose, among alternative general policies, those that on average tend to produce more favorable, if not optimal, results (118:28). Effective competition is one way of identifying specific dimensions in a market which can be influenced by policy toward such more favorable results.

Most proponents of effective competition admit the extent to which it relies on the judgment of the analyst. As Markham explains, "The concept owes its creation to a public policy need and not to the logic of abstract theory. It can, at best, be divorced only in part from value judgments" (94:349). The role of judgment becomes most critical in those cases when the evidence about an industry is mixed. What combination of criteria met and unmet is acceptable? According to Sosnick, an industry is clearly and unambiguously effectively competitive if and only if it meets all criteria (129:850). Other cases will only indicate, strongly or not, that further investigation is warranted.

In fact, Papandreou and Wheeler argue that it is undesirable that public policy attempt to enforce all criteria of workable competition (107:18-19). They agree with Sosnick's assertion that the judgments in an effective competition analysis that pertain to a social value system are what make the concept useful to public policy (107:204-207; 128:382). Policy is a reflection of the prevailing social value system. If values change, policy responds, sooner or later. If the operative concept of effective competition in an analysis also reflects a value system in its definition of social welfare, it will provide a clear indication in those cases where the market situation strongly differs from the norm. That the value system changes over time does not affect the usefulness of such an analysis at the particular moment. Maintaining effective competition through continual analysis and enforcement, say Papandreou and Wheeler, is "the only meaningful alternative to a planned society" (107:204).

Effective competition has not been proposed as a theory to vie with the traditional models, but only as a means by which judgment can be applied within a framework of economic values. The traditional models, as has been described, have been found to be of very limited value for policy-making. Analysts like Markham have found industries which do satisfy all their criteria, demonstrating the usefulness of the concept for evaluating actual situations. That the value systems underlying such analyses change does not render these studies useless, only subject to periodic reexamination.

Indeed, continued monitoring is in line with Clark's concept of a dynamic market, where time is a key dimension in the model.

Effective competition, then, is a rough but useful tool for economic analysis aimed at framing public policy. That it is reliant on value judgments does not detract from its usefulness when the underlying concept of social welfare is clearly identified. It does not purport to produce a set of instructions for antitrust action, but only indicates where such investigations may be fruitful. It does not provide a guaranteed cure, but it can at least pull together the symptoms for an effective diagnosis.

Criteria

What, then, are the criteria--the symptoms--by which to diagnose if effective competition exists in a particular industry? Almost every writer on the subject has proposed his own list, and each list has its idiosyncracies. Since Sosnick has thoroughly reviewed the literature on the subject, this section will simply review his two articles, addressing the significant change in approach between the two, compare his views with those of his predecessors, and attempt to derive some consensus on the critical aspects of a market to look for.

In his "Critique of Concepts of Workable Competition," Sosnick summarized the most frequently-mentioned market characteristics identified in the works of eighteen economists, dividing them into three categories, as shown (128:389-391):

1. Structural norms:
 - a. A large or an appreciable number of traders, or several at least, none dominant; or as many as scale economies permit.
 - b. Moderate and price-sensitive quality differentials.
 - c. No artificial handicaps on mobility.
 - d. Adequate access to information.
 - e. Some uncertainty whether a reduction in price will be met.
 - f. Absence of legal restriction.
 - g. Continued opening of fresh areas and types of competitive contact.
2. Conduct criteria:
 - a. Firms should strive in rivalry without collusion.
 - b. Firms should not shield permanently inefficient rivals, suppliers, or customers.
 - c. There should be no unfair, exclusionary, predatory, or coercive tactics.
 - d. Persistent price discrimination should not occur.
 - e. Sales promotion should not be misleading.
 - f. Buyers should react fairly rapidly to differential offerings.
3. Performance criteria:
 - a. Operations should be efficient.
 - b. Promotion expenses should not be excessive.
 - c. Profits should be at levels which reward investment and efficiency and induce innovation.
 - d. Output should be consistent with a good allocation of resources.
 - e. Prices should not intensify cyclical instability.
 - f. Quality should conform to consumers' interest.
 - g. Opportunities for better products and techniques should not be neglected.
 - h. Conservation should not be disregarded.
 - i. Success should accrue to sellers who give buyers more of what they want.
 - j. Entry should be as free as the nature of the industry permits.
 - k. The industry should aid in national defense.
 - l. Small groups should not hold excessive political and economic power.
 - m. Employee's welfare should not be neglected.

Despite the number of items listed in the category of structure, Sosnick argues that structural norms are by far the least important (128:402-405). This is because there is often no clear answer to the question of what effect a structural condition--say, the number of sellers--has on performance.

Moreover, there may be no way to predict what effect a public policy to change a structural condition may have on performance. If there are three sellers, would performance improve if there were five? Fifteen? Fifty? For this reason, he recommends that structure be divided into its malleable and intrinsic aspects (128:416). The malleable aspects are those which public policy can, within reason, influence. The intrinsic aspects are determined by nature, technology, chance, or other factors beyond the control of government--the basic conditions of the market.

Since the aim of effective competition is to identify where feasible changes would improve social welfare, Sosnick maintains that no characteristic should be labelled "satisfactory" unless its present state is unimprovable. For a condition to be improvable requires that (128:409):

1. At least one change that would improve performance is possible.
2. Some reasonable remedy to accomplish the change is available.
3. The direction and strength of the effects be predictable, including the effects of employing the remedy.
4. The desirable effects must outweigh the undesirable.

Sosnick then lists his own set of criteria, "a compromise between mentioning every difference among markets and referring to only a few oversimplified variables" (128:416). Many of the items agree with the list culled from the literature, but in most cases, Sosnick provides a much more complete description of the criterion than previously available. His criteria are:

1. Performance Dimensions.

- a. Economic profits should correspond to the enterprises' risks, innovations, and costs.
- b. Volume of sales should equal demand without continued excess demand or inventory backlog.
- c. Opportunities to reduce costs or improve products should not be suppressed or neglected; obsolescence should be corrected with reasonable speed.
- d. Costs should be minimized over the relevant time span.
- e. Promotion should be informative, providing buyers the opportunity to be rational in their choices.
- f. Product quality and variety should be appropriate within the forces of economy and individuality.
- g. Sellers and buyers should be lawabiding and mindful of social responsibilities.
- h. Producers should favorably influence inputs, insuring that natural resources are not exhausted.
- i. Labor-management relations should not be characterized by frequent shutdowns, exploitation, or excessive wage increases. Working conditions should be desirable.
- j. Management should strive for the most profitable longterm return on equity, except where it would conflict with social welfare.
- k. Concentrated economic power should be justified, and protections should exist against its abuse.

2. Conduct Dimensions.

- a. Enterprises should not employ unfair tactics against actual or potential competitors.
- b. Collaboration among firms should not promote their own welfare to the detriment of others.
- c. Resale price limits should not be set.
- d. Economic discrimination should not prey on weaker sellers or disadvantage small buyers.
- e. Methods of trade should be the most convenient and not be conducive to exclusion or price leadership.
- f. Aggressiveness in rivalry and bargaining should be stronger or weaker if that would improve performance.
- g. Buyers and sellers should be responsive to changes that improve performance.
- h. Sellers should disregard insignificant or ephemeral price changes, unless greater price flexibility is justified.
- i. Mergers should not change the structure of any market in contravention of the norms for concentration or conditions of entry.

3. Malleable Dimensions of Structure.

- a. Interlocks should not unjustifiably threaten competitors or raise questions of conflict of interest.

- b. Buyer and seller concentration should not be such that a change would improve performance.
 - c. Turnover should continually weed out truly less dynamic and efficient firms, but at rate that allows the reabsorption of resources.
 - d. Size, number of plants, integration, and markets should represent a search for growth and efficiencies.
 - e. Trade associations should not facilitate harmful collaboration.
 - f. Standardization and commonality should be pursued if it improves selections and reduces costs of use.
 - g. Information should be easily available to buyers and sellers.
 - h. Conditions of entry should be such that no change would tend to improve performance.
 - i. Legal controls should favor optimal performance.
4. Intrinsic Dimensions of Structure.
- a. Product attributes, including durability, cost, storeability, transportability, complexity.
 - b. Production characteristics such as period of production, inventories, inputs, unionization, and number and skills of employees.
 - c. Marketing features, including buyer uses, codes of ethics, frequency of purchase, order delivery lag, and importance of design to buyer.
 - d. Organizational aspects such as partnerships, trusts, ownership, finances, planning horizons.

Ten years after this article, Sosnick offered a considerably different list (129). In his article, "Toward a Concrete Concept of Effective Competition", Sosnick established seven principles to follow in developing criteria: "[B]e specific, definite, explicit, realistic, discriminating, comprehensive, and stringent" (129:829). He then listed 25 market conditions which were verifiable, undesirable, and remediable. Of these, 10 were undesirable in themselves, while 15 were undesirable only because of their effects (129:842). Items 1 through 7 and 11 relate to performance, items 8 through 10 and 12 through 22 to conduct, and 23 through 25 to structure (129:843-851):

Conditions Undesirable in Themselves

1. Unsatisfactory products.
2. Underuse or overuse.
3. Inefficient exchange.
4. Inefficient production.
5. Bad externalities--inflicting costs which could be avoided.
6. Spoliation--needlessly exhausting nonrenewable resources.
7. Exploitation.
8. Unfair tactics.
9. Wasteful advertising.
10. Irrationality--self-defeating choices by buyers or sellers.

Conditions Undesirable in Their Effects

11. Undue profits or losses--for example, positive profits when there is an inferior combination of quality and prices.
12. No research into reducing costs or improving products.
13. Predation.
14. Freemption.
15. Tying arrangements.
16. Resale price maintenance.
17. Refusals to deal.
18. Discrimination not justified by difference in costs.
19. Misallocation of risk.
20. Undesirable collaboration.
21. Undesirable mergers.
22. Undesirable entry.
23. Misinformation.
24. Inefficient rules of trading.
25. Misregulation.

This list departs from the structure-conduct-performance norms approach, but it has the advantage of speeding up the diagnosis by identifying those factors whose existence is sufficient to keep an industry from being effectively competitive. It is also clearer than his previous list, which was full of openings for subjective judgment to enter: "Producers should exert whatever favorable influence is needed and reasonably available on the quality, availability, training, and absolute and relative prices of inputs" (126:417).

Sosnick also abandons most of the structural criteria proposed in the literature. He gives several reasons for this (129:837-838). One is that there has never been a consensus of what is a satisfactory level of concentration or barriers to entry. Another is that even if such a consensus is reached, these conditions do not necessarily imply satisfactory performance. He does, however, emphasize that while such structural conditions do not constitute necessary or sufficient reasons for determining the extent of competition in an industry, they must be addressed as part of the overall analysis, for the clues they give to the interaction of all elements of the structure-conduct-performance triad (129:839).

What are the significant changes in the criteria from the first articles on workable competition to Sosnick's last list? Sosnick began his article by stating his goal of developing "meaningful and manageable criteria" (129:828). Richard Low and others have pointed out the flaws in approaches like Markham's and Edwards', stressing both that their criteria were not necessary or sufficient conditions and that their criteria were of little use in practice (91:46-47; 60:29). By keeping the aim of the concept in mind, Sosnick came closer to providing a means of assessing situations so that opportunities for remedy by public policy could be identified.

Norris Pritchard complained that Sosnick's second list expressed its standards in "purely negative terms" (112:477). Yet, by approaching the subject in this way, Sosnick adopts

the approach of public policymakers. Antitrust laws do not state what situations are acceptable, but identifies those that work against the social good. Rather than presuming a set of norms for all industries, he attempts to identify every market condition that is undesirable, verifiable, and avoidable.

These three characteristics--undesirability, verifiability, and avoidability--are what make Sosnick's list particularly useful for the analyst attempting to assess the need for change in the public policies affecting a market. If a condition is not undesirable, while there may be interest in looking into how the government can encourage its continued presence, there are probably also strong arguments against tampering with the market forces. If a condition cannot be verified as being present in an industry, there is no point in talking about remedies. If it is not avoidable--due to the control of essential inputs by a foreign power, for example--it lies beyond the realm of social control. If an undesirable condition can be observed in the market, the analyst can try to determine why it exists, and then evaluate possible policy changes.

For these reasons, this study uses the set of criteria listed on page 33 to assess the character of effective competition in the spacecraft market. Before leaving the subject of effective competition, however, it is essential to at least identify the underlying concept of social welfare from which any value judgments in this study are made.

The principles that guide the government's influence in economic activity are that all persons should enjoy at least some minimum set of economic conditions necessary for a healthy life, that economic power should not exploit or exalt private interests over those of the public, and that resources should be used efficiently to maximize output (93:185-6). The first principle is a matter of equity in the distribution of income and other benefits. The second is reflected in policies aimed at reducing monopoly power in markets. The third, efficiency, embodies efficiency in consumption, in production, and in the sovereignty of consumers to choose among alternatives (122:59).

In looking at defense markets, this last principle, efficiency, seems the most important. As Richard Garwin has written, in spending for national security, "A dollar spent unnecessarily is a dollar of military capability denied us" (69:24). Given the significant trend toward increasing unit costs in defense programs, the ability of producers and program managers to minimize their cost curves and optimize their output is the real proof of whether a particular defense market is or is not serving the welfare of the public.

With these values and the criteria provided in Sosnick's second list in mind, particularly those concerning aspects of efficiency, this study will look at the specific characteristics of the defense spacecraft market.

III. Development and Structure of the Market

This chapter opens with a brief description of the genesis of the military space program in conceptual studies undertaken in the decade following World War II. It outlines how the industry took shape, beginning with development of experimental systems and quickly evolving into the production of operational systems. With this historical perspective, the structure of the industry since 1978 is examined. A definition of the industry is offered, and its size is described and compared with that of the overall aerospace industry. The degree of concentration among sellers and buyers is estimated, and the conditions of demand and supply are discussed. It evaluates barriers to entry into the industry, then focuses on the question of subcontracting and coalitions in the DOD market which influence its conduct and performance.

Origin and Early Evolution of the Military Space Program

Since this study focuses on the military space market, it is useful to begin with a look at its genesis and early growth. The market for military space vehicles was born in the conceptual studies conducted by the Navy and Army Air Corps during the 1940's. The Navy study was in part contracted to the California Institute of Technology's Guggenheim Aeronautical Laboratory, which later became the Jet Propulsion Laboratory, a major developer and producer of scientific space vehicles. The Army's study was contracted to Project RAND,

originally a branch of the Douglas Aircraft Corporation, with participation by North American and Northrop (79:69-75). These were feasibility studies that looked into possible military uses for artificial satellites, suggested tentative designs, and outlined technological considerations (82:35).

These studies were remarkable in their prescience. A 1949 RAND report identified four of what have become the five primary military uses of satellites: communications, reconnaissance, surveillance, and meteorology--only navigation was not mentioned (79:89). None of these efforts resulted in any significant hardware development, however, largely because, although the subject was deemed worthy of development, no firm military requirement could be identified (79:85).

The first such requirement arose from the acceleration of the ballistic missile program (82:36). Several factors came together to promote satellite development. The recommendation of the Strategic Missile Evaluation Committee in February 1954 to accelerate ballistic missile development meant that the rocket technology required to launch reasonably heavy satellites would be available for a space program. Second, fears about Soviet missiles stimulated the desire for photo reconnaissance and missile launch detection, missions similar to those proposed in the early studies. In March, 1955, the Ballistic Missile Division issued a request for proposal for WS-117L, a prototype photo reconnaissance satellite system (97:238). Of the three bidders, Lockheed was selected to develop the prototype system because it had a proven record of

building aircraft for the government (82:66).

Although the WS-117L program was approved, it took the dramatic launch of Sputnik in 1957 to provide the political momentum needed to push a full-scale military space hardware development program through (135:36). Ironically, the impact of Sputnik had been predicted over ten years earlier in the first RAND report for the Army Air Corps, which stated:

Since mastery of the elements is a reliable index of material progress, the nation which first makes significant achievements in space travel will be acknowledged as the world leader in both military and scientific techniques. To visualize the impact on the world, one can imagine the consternation and admiration that would be felt here if the U.S. were to discover suddenly, that some other nation had already put up a successful satellite" [79:75].

Suddenly, the gap between U.S. and Soviet programs had international attention. Military and civilian decision-makers quickly began to work to close the gap, accelerating on-going programs like WS-117L and Vanguard, and giving new programs the go-ahead. Less than two months after Sputnik, for example, the Air Research and Development Command had already prepared an astronautics program, pulling together its current space projects and prioritizing potential efforts (130:44).

One of the biggest decisions to be made was about who would be responsible for military space programs. The Air Force's Ballistic Missile Division, the Navy's Naval Research Laboratory, and the Army's Redstone Arsenal were all engaged in developing experimental satellites and space boosters, and the Vanguard program was being undertaken as a strictly civilian effort. The Advanced Research Projects Agency (ARPA) was

established in November 1957 to coordinate all military programs, while the National Aeronautics and Space Administration (NASA) was formed in April 1958 to manage civil/scientific air space research. However, interservice rivalry continued, and responsibility was transferred back to the services from ARPA in September 1959. When the Kennedy administration took office, Secretary of Defense McNamara ordered a review of the organizations for military space research and development. Based on its findings, he issued DoD Directive 5160-32, "Development of Space Systems," which gave the responsibility for full-scale development to the Air Force (135:40-43).

These years were marked by tremendous growth. The first U.S. military satellite, Discoverer I, was launched on 28 February 1958. Along with WS-117L, which was known as Discoverer in its test phase, programs to develop missile launch surveillance (Midas), navigation (Transit), weather (Tiros), communications (Advent) and a manned space glider (Dynasoar) were underway by 1960 (130:45-77). The budget for military space programs grew from \$1 million in 1955 to \$490 million in 1959 (6:52). Similarly, the conceptual and organizational structure by which these programs were to be managed was established:

By the end of the Eisenhower administration, the foundations of each of the major military space programs had been laid. Similarly, between October 1957 and October 1963 the policy guidelines that have determined the subsequent U.S. exploitation of space were also formulated (56:36).

The industrial base to support the space programs was also

formed during this time. The companies that had participated in a decade's worth of studies were ready to reap the rewards of their recently-acquired expertise. RCA, for example, was involved in RAND studies in 1949 and 1951, and was one of three companies selected to conduct feasibility and design studies for what was to become the WS-117L system, incorporating the Discoverer, Samos, and Midas programs. Although its design was rated the best of the three by the source selection evaluation board, it lost the full-scale development contract to Lockheed on the basis of experience. Looking for a way to employ its new experts in satellites, RCA went to the Army Ballistic Missile Agency, which it sold on the idea of developing a system to provide television pictures of Earth from a satellite (82:66-68).

This project eventually ended up in the hands of NASA as the Television Infrared Observation Satellite (Tiros). The first Tiros, built at a cost of \$10 million, was launched in April 1960. It was a tremendous success, producing useful weather pictures on a regular basis, and in 1961, President Kennedy went forward with a \$75 million program for an operational weather satellite system (82:68).

Many of the space contractors also capitalized on their experience in guided missile work. General Electric, which pioneered work in ballistic missile nose cones and guidance systems, entered the space field as the contractor for the Discoverer re-entry system, and quickly won contracts to develop meteorological and scientific satellites (65:123-5). By 1961,

sales from space vehicle projects equalled those from nose-cone work (65:125).

The Rise of Systems Engineering. Guided missiles and space vehicles were not, however, like aircraft or anything else the military had demanded or that these companies had produced. On the buyer's side, the Air Force found these systems presented both technological and managements challenges. These systems were the most complex structures that had been built at the time, comprising thousands of components, subsystems, and unique devices. With the number of subsystems, scientific and engineering specialties, and organizations involved, the task of coordinating and managing these efforts required skills combining engineering and management--systems management (or systems engineering), as the field came to be called. A 1953 Air Force survey headed by John von Neumann found that no single major aerospace company could handle the production and integration of the nose cone, missile structure, propulsion, and guidance systems (82:61).

Around the time of the von Neumann study, Simon Ramo and Dean Wooldridge, engineers, vice presidents of Hughes Aircraft, and members of the von Neumann committee, formed the Ramo-Wooldridge Corporation, with capital support from the Thompson Products to offer systems management support to the military (97:107). In 1955, Ramo-Wooldridge was selected as systems engineers for the ballistic missile program, and soon became an integral part of the Ballistic Missile Division management (100:15). By 1957, when it formally merged with Thompson

(creating TRW), the firm had over 3,000 employees with \$29 million in assets. Its fees for providing technical advice to the Air Force averaged 14% of the estimated cost of contracts supervised (82:62).

When Thompson took over management of Ramo-Wooldridge, it set up a subsidiary, Space Technology Laboratories, to carry on the consulting work, while TRW competed for hardware contracts. The aerospace industry argued that this constituted an unfair advantage. In June, 1960, with pressure from Congress, TRW and the Air Force created a nonprofit corporation, the Aerospace Corporation, with the sole responsibility of providing technical support to government space programs (82:63). It continues to function in this role today.

The same problems of developing and producing complex space systems faced the contractors as well. As early as 1962, both business and academic observers were noting the profound effect the complexity of these systems had on the pattern of business. Peck and Scherer found that over 50% of the proceeds from military contracts were passed on through interbusiness transactions (108:386). Fortune magazine, echoing the von Neumann committee findings, concluded that "no single company yet has the immediate resources to manufacture whole vehicles" (65:88). Companies attempted to offset the loss of revenues to subcontractors by working as subcontractors themselves on other contracts, thus offsetting the revenues lost to their own subcontractors while fully utilizing the resources in their particular area of specialization. But the figures on

subcontracting--4,000 subcontractors to McDonnell on the Mercury capsule contract alone--testified to the magnitude of the technical and management effort required to produce a space vehicle.

In these early stages, then, space ventures were almost exclusively the realm of the government and the military. Only one company, American Telephone and Telegraph, saw enough commercial potential in space to undertake its own satellite research and development effort. Key developments in communications technology, such as the transistor, large horn antennas, solar power cells, and low-noise radio receivers, resulting from Bell Laboratories' aggressive research program, made feasible a communications link using a satellite as a relay antenna (82:161-2). By 1960, these technologies had been integrated to the point that AT&T contracted with Douglas for a series of Delta rockets to launch its experimental satellites (82:164). Telstar, first launched in 1962, was the first satellite built with private funds, and the first to provide voice, data, and television links between continents (97:358).

Within a year after the first Telstar launch, both RCA and Hughes had launched communications satellites. However, President Kennedy was concerned about AT&T's ability to establish a monopoly on satellite communications, and political pressure resulted in the creation of the Communications Satellite Corporation (Comsat), to provide a commercial satellite communications system (82:168). AT&T became a major stockholder in Comsat, and withdrew from the satellite

manufacturing business.

The Space Industry Matures

In July, 1959, the Aircraft Industries Association changed its name to the Aerospace Industries Association, to reflect the industry's "new role as the supplier of vehicles and equipment for space exploration" (9:87). As a proportion of the total industry workload, space equipment ranked third behind aircraft and missiles, but the intensified launch schedule for prototype systems and the rapid progress on full-scale development programs represented a significant demand on manpower and facilities (10:88). Some companies, like Martin, even left the aircraft business completely for the missiles and space field. A Martin executive was quoted as saying, "We don't expect to ever design and produce another aircraft" (10:133). A special issue of Fortune magazine devoted to the subject in 1962 concluded that "the space effort alone will add the equivalent of a good-sized industry to the economy" (65:85).

Almost all public attention was focused on NASA's portion of the space effort. President Kennedy's speech to the Congress on 25 May 1961 stated his belief that the United States "should commit itself to achieving the goal, before this decade is out, of landing a man on the moon and returning him safely to earth" (97:303-4). The race to the moon consumed public interest and much of the budget for space through the 1960s (see Table I). There was a decline in NASA programs following the end of the Apollo program, but Skylab and

Table I.

Expenditures for Space Activities by Agency: 1955-1984
(Millions of Dollars)

Fiscal Year	Dept. of Defense Total	Percent. of Total	NASA	All Agencies Total
1955	\$ 1	1.3 %	\$ 74	\$ 75
1956	17	17.0	71	100
1957	48	32.0	89	150
1958	136	26.1	146	521
1959	490	62.4	261	785
1960	561	52.6	462	1,066
1961	814	45.0	926	1,808
1962	1,298	39.4	1,797	3,295
1963	1,545	28.4	3,626	5,435
1964	1,599	23.4	5,016	6,831
1965	1,574	22.6	5,183	6,956
1966	1,689	24.2	5,065	6,970
1967	1,664	24.8	4,830	6,710
1968	1,922	29.4	4,430	6,529
1969	2,013	33.7	3,822	5,975
1970	1,678	31.4	3,547	5,341
1971	1,512	31.8	3,101	4,741
1972	1,407	30.8	3,071	4,575
1973	1,623	33.6	3,093	4,825
1974	1,766	38.1	2,759	4,640
1975	1,892	38.5	2,915	4,914
1976	1,983	37.3	3,225	5,320
1977	2,412	40.3	3,440	5,983
1978	2,457	39.7	3,582	6,188
1979	2,891	42.5	3,744	6,808
1980	3,162	41.2	4,340	7,667
1981	4,131	45.1	4,877	9,165
1982	4,772	45.6	5,453	10,466
1983	6,290	49.4	6,146	12,720
1984	7,504	52.9	6,385	14,192

Sources: 5:53; 41:67.

Table II.

Number and Average Weight of U.S. Payloads Launched, 1960-1980.

1960	11 payloads	83 rd kilograms per payload
1965	46	863
1970	30	1023
1975	13	2273
1980	15	2769

Source: 135:53.

development and production of the Space Transportation System maintained NASA's majority share of the space budget.

Although over half of the payloads launched into orbit by 1962 were military, these programs willingly conceded the limelight to the manned space programs (97:272). In 1961, National Security Advisor McGeorge Bundy extended a media blackout over the Discoverer program, and most other programs maintained a low profile for security reasons (97:346).

The military continued to launch a high number of payloads per year through the early 1970s. These were for surveillance, communications, navigation, meteorological, and unannounced classified programs, all of which had transitioned from advanced development and test into full-scale operations by this time. Beginning about 1972, however, the number of payloads began to decrease. This should not be interpreted as indicating a shrinking military space program. As shown in Table 2, while the number of payloads decreased, the average weight per payload increased, as designers exploited the increase in lift capabilities due to larger boosters by building heavier satellites with greatly extended lifetimes.

The lifetime of a Defense Meteorological Satellite Program (DMSP) vehicle, for example, went from less than two years in 1965 to over six by 1977 (114:4-5).

On the industry side of the space market, companies began to catch up with the surge in demand for space systems in the early 1960s. New facilities for development and production of space vehicles were built, and these operations were formally established as divisions in their corporate organizational structure. In 1961, General Electric Space Systems Division moved into its Valley Forge Space Technology Center, which centralized advanced development facilities and research laboratories with space program management offices (11:100). RCA opened similar facilities for its Astro-Electronics Division in Princeton, NJ, as did Hughes, and North American, which redesignated its Missile Division the Space and Information Systems Division (11:133). Grumman spent approximately \$2.7 million on space test facilities, including a 15'x20' environmental space chamber to simulate the thermal and vacuum conditions of low earth orbit, a shaker stand to subject spacecraft to vibrations like those encountered in launch, a centrifuge, air bearing tables to test guidance and control systems, and a clean room in which the major subsystems and spacecraft could be assembled (11:110).

Throughout the 1960s, companies consolidated and expanded their space facilities. Boeing spent over \$20 million on its Space Center in Kent, WA, while Douglas Aircraft's investment in its Space Systems Center in Huntington Beach, CA totaled \$35

million by 1966 (12:95,101). Ling-Temco-Vought and Fairchild-Hiller completed Space Technology Centers in the late 1960s, each for over \$25 million (13:80; 14:126).

Some of these facilities were quickly made obsolete as larger and more sophisticated spacecraft were developed. Martin Marietta spent \$5 million in 1967 on a 24'x36' thermal vacuum chamber to accommodate spacecraft too large for its smaller chamber; a year later, TRW added a similar chamber (14:132; 15:168). The cost of such facilities motivates some manufacturers to cooperate with their competitors. Ford Aerospace, for example, used Lockheed's acoustical test cell to check out its Intelsat V satellites (81:103).

By 1963, all of the current members of the spacecraft industry had entered the market; by 1972, most of the other participants had exited. Northrup built one scientific satellite, the OV2, then never won another contract and shut down its spacecraft operations. Grumman did not build another spacecraft after the Orbiting Astronomical Observatory, but it has recently begun to compete for Space Station, Transatmospheric Vehicle and other advanced development contracts, and has announced it will form a Space Systems Division if it wins any of these (133:V-9, V-19; 5:26 Feb 85).

During the 1970s, the rate of growth of the industry slowed, and even declined slightly immediately after the last Apollo mission. The DOD share of the space budget, however, grew steadily from less than one-third to over one-half by 1982. The members of the industry further developed their

expertise in particular space technologies, and thus, insured their share of the market. Hughes, which had built the first geosynchronous comsat, became the predominant firm in the new commercial comsat market, followed by RCA and Ford Aerospace. Rockwell retained its leading share of the NASA market by winning the Space Shuttle prime contract. By the late 1970s, the essential characteristics of the current market structure had begun to form.

Structure of the Spacecraft Market

In his book, *Industrial Organization*, Joe Bain defines market structure as "those characteristics of the organization of a market that seem to exercise a strategic influence on the nature of competition and pricing" (19:7). The following set of structural characteristics are those most commonly used in industry studies, and will be used in this study (98:9-10):

1. Distribution of sellers by number and size--seller concentration.
2. Distribution of buyers by number and size--buyer concentration.
3. Conditions of demand and nature of the product.
4. Conditions of supply and technology.
5. Conditions of entry to and exit from the market.
6. Influence of government regulations and policies.

The most critical step in analyzing the structure of an industry is defining what comprises the industry. A properly defined industry groups firms in a way that best enables one to understand their behavior (28:91). To be effective, the definition must account for substitution in production and consumption. Firms in the same industry should possess similar facilities and employ similar skills. Their products should be

close substitutes for each other's in the eyes of the consumer, if not actually homogeneous.

Most of the literature on defining industries focuses on substitutability of demand (28:89-90). This substitutability is often measured by the cross-elasticity of demand. The cross-elasticity of two products, A and B, is measured by the percentage change in the quantity of A demanded caused by a percentage change in the price of B. Thus, if A and B are close substitutes, an increase in the price of B would be reflected in an increase in demand for A.

Cross-elasticities, however, are often difficult to measure and do not always provide a practical tool for defining industry boundaries. Boyer has proposed an approach that defines the industry from the firm's viewpoint (28; 29). To define an industry, he suggests, begin by focusing on one output and assume it to be the sole product of of a firm. Then look at that subset of the universe of sellers such that this group could exercise monopoly power over this output, if such collusion were legal. This group of firms can be defined as the industry producing that output. "In effect, the industry defined for some output is its producer's ideal cartel" (29:763).

This approach parallels Porter's belief that structural analysis should focus on the sources of competition perceived by the firm (110:32). A firm's competitors are those sellers that would be able to inflict significant losses by drawing away sales if that firm acted as if it had monopoly power. The

limitation on the selection of firms is that inclusion of a firm must significantly improve the group's advantage; to the same extent, exclusion of a particular firm should not lessen the group's advantage to a measurable degree. This definition accounts for both substitutability considerations. The collusive group would be constituted in such a way that its behavior would not be constrained by the decisions of competitors in the short run. Thus, producers with dissimilar facilities and expertise would not be placed in the same industry, nor would firms which sell to significantly different customers. The collusive group serves to limit the analysis to those sources of competition that most affect the firm's competitive strategy.

An industry definition must also deal with the problem of potential competition. Boyer's solution is to "include all holders of assets necessary to complete a cartel regardless of whether the assets currently are or are not used to produce demand substitutes" (29:767). Porter's criteria for identifying potential competitors uses similar logic (110:50):

1. Firms that could cheaply overcome entry barriers
2. Firms that have an "obvious synergy" with firms active in the industry
3. Firms for whom competing in the industry is an obvious competitive strategy
4. Customers or suppliers who may integrate backwards or forwards into the industry.

The product in this study is spacecraft--systems designed to operate as artificial satellites of Earth, to travel on interplanetary missions, or, in the case of the Space Shuttle, to orbit and return to Earth. Also included in this definition

are upper stage systems, which are propulsion units designed to lift payloads from low earth orbits into medium or geosynchronous orbits.

These units are included for two reasons. First, these units are similar to satellites in a number of ways. Some are equipped with sophisticated guidance and control systems, incorporate propulsion units in their structure, and are designed to operate in the harsh space environment. The control systems, in particular, separate them from simple propulsion units and make them similar to satellites from the production side. The facilities required to build upper stages are essentially identical to those required to build spacecraft--thermal vacuum chambers, clean rooms, and vibration stands. These facilities could handle space vehicles without major modifications.

Second, the firms currently producing upper stages--General Dynamics, Boeing, McDonnell-Douglas, and Martin Marietta--have been engaged in manufacturing spacecraft in the past, and are presently competing for Strategic Defense Initiative research and development contracts (133). They are clearly perceived by spacecraft manufacturers as competitors--in fact, Ford Aerospace, and Hughes have each announced satellite designs which integrate propulsion systems to eliminate the need for a separate upper stage. These designs are intended to attract customers seeking an alternative to the high cost of the current complex upper stages (37; 64; 83).

Thus, the upper stage manufacturers meet Porter's

criteria for potential competitors, and would have to be included in the "ideal collusive group" of any spacecraft manufacturer. This group would include both firms currently producing satellites and those capable of developing competitive proposals for new spacecraft system contracts with NASA, DOD, or commercial customers. If these companies were allowed to collude in bidding for contracts, they could allocate contracts among themselves so that no firm would be opposed in its bid. The group would thereby increase its profits by eliminating the costs preparing competitive proposals. These are major costs--McDonnell-Douglas attributed much of a 178% decline in earnings in its missiles and space segment between 1983 and 1984 to "high proposal costs incurred in bidding on new space programs" (5:30 Jan 85).

This group does not include research organizations such as Lincoln Laboratories of MIT, the Jet Propulsion Lab of Caltech, the Applied Physics Lab of Johns Hopkins University, or the Naval Research Lab, which have built spacecraft for scientific purposes. These facilities have restricted their activities to research efforts, and have official (DARPA, NASA, U.S. Navy) or quasi-official connections with their clients. While all of the companies above have competed for or built scientific spacecraft, the research organizations have not competed for commercial or operational military systems. Their motivations are more scientific than economic, and do not really operate in the context of a market model.

The firms included in the spacecraft industry, as defined

Table III.

Spacecraft Manufacturers.

Satellite Manufacturers

Ball Corp.
Fairchild Space Co.
Ford Aerospace and Communications Corp.
(subsidiary of Ford Motor Co.)
General Electric Co.
Hughes Aircraft Co.
Lockheed Missiles and Space Co.
RCA Corp.
Rockwell International Corp.
TRW Inc.

Upper Stage Manufacturers

The Boeing Co.
General Dynamics Corp.
Martin Marietta Corp.
McDonnell-Douglas Corp.

Sources: 140; 143.

in this study, are listed in Table III.

These companies are, for the most part, very large corporations, and constitute the core of the defense and aerospace industries. The seven top DOD contractors for Fiscal Year (FY) 1984 were all firms participating in the space industry (5:26 Apr 85). Table IV lists the respective rankings of the firms in terms of total DOD procurement, DOD research, development, test, and evaluation (RDT&E), and NASA contract dollars awarded in FY 1984, as well as their ranking in the 1985 Fortune "500." (Several firms are not listed because they were ranked in less than three categories.)

These companies operate in a wide number of industries. Table V lists the number of four-digit SIC industries each firm

Table IV.

Rankings of Spacecraft Industry Firms.

Company Name	DOD Contracts (FY 84)	DOD RDT&E Contracts (FY 84)	NASA Contracts (FY 84)	Fortune 500 Ranking by Sales (1985)
McDonnell-				
Douglas	1	7	4	34
Rockwell	2	3	1	37
General Dynamics	3	6	6	44
Lockheed	4	2	5	43
Boeing	5	1	9	29
General Electric	6	4	15	9
Hughes	7	8	20	(not ranked)
Grumman	11	22	--	146
Martin Marietta	12	5	2	85
Ford	20	120	11	4
RCA	22	23	18	(not ranked)
TRW	24	10	21	59

Sources: 5:26 Apr 85, 30 Apr 85; 8:159; 62.

Table V.

Total 1984 Sales, Employees, and SICs Active In, by Company

Company	Sales in \$M	Employees	# of SICs
Ball	\$ 909	9,600	8
Boeing	11,130	88,824	5
Fairchild	892	13,500	9
Ford	44,450	380,077	23
General Dynamics	7,140	92,600	17
General Electric	26,800	404,000	10
Hughes	(not reported)	58,800	12
Lockheed	6,490	79,400	12
Martin Marietta	3,900	40,200	16
McDonnell-Douglas	8,110	85,589	13
RCA	8,980	119,000	10
Rockwell	8,100	103,500	22
TRW	5,130	85,099	7

Source: 134.

is active in, as well as 1984 sales and employees. For most companies, however, space systems are not a major source of sales. In 1984, the space operating divisions accounted for less than 5% of total sales for Boeing, Ford, GE, General Dynamics, and RCA (101).

Size of the Industry. While space sales do not account for a large percentage of sales for most companies, the space industry has surpassed missiles in its share of total aerospace industry sales (8:15). Over the period from 1978 to 1984, sales of space products increased at an average annual rate of 19.2%, compared to 15.6% for missiles and 12.3% for aircraft. By 1984, space sales represented over 20% of the total for aerospace (5:20 December 1984). With the increase in SDI contracts and commercial satellite sales, combined with declining airliner sales due to foreign competition, space

Table VI.

Shipments to the DOD by Industry, 1983.

SIC	Industry	Employees (thousands)	Sales (\$M)
3662	Radio & TV Comm. Equipment	230.6	\$ 18,135.5
3721	Aircraft	146.7	15,622.1
3761	Guided Missiles & Spacecraft	76.6	8,750.4
3724	Aircraft Engines	58.2	6,866.1
3731	Shipbuilding	88.7	6,099.3
3728	Aircraft Equipment and Parts	59.7	4,930.8
2911	Petroleum Refining	22.0	3,493.8
3795	Tanks	14.0	2,288.0
3573	Electronic Computing Equipment	18.0	1,741.1
3483	Ammunition (except small arms)	24.1	1,360.9

Source: 48.

growth will continue to outpace aircraft sales. In terms of shipments to the Department of Defense, the combined guided missiles and space industries (SIC 3761) were the third largest defense industry in the U. S. in 1983, accounting for over 10% of total shipments (see Table VI).

Employment in the missiles and space industries also grew at a faster rate than aerospace during this period--an average annual rate of 9%, compared to an average of 2% for the overall aerospace industry (see Table VII). During this period, the share of aerospace employment accounted for by missiles and space workers grew from 9.5% to 12.4%. Here again, the increase in share of total aerospace employment reflects both an increase in space contracts and a decrease in aircraft production.

There are three groups of customers for spacecraft: commercial satellite communications companies and consortiums,

Table VII.

Employment in Missiles & Space and Aerospace
Industries: 1978-1983.
(In Thousands)

Year	Missiles & Space		Aerospace	
	Total	Production	Total	Production
1978	93	29	941	476
1979	102	33	1109	562
1980	111	35	1185	598
1981	123	37	1201	590
1982	132	41	1162	545
1983	143	46	1151	522

Source: 8:57-58.

Table VIII.

Value of Net Sales of Space Vehicle Systems and Parts, 1977-1983
(By Customer, in Millions of Dollars)

Year	Military	Nonmilitary		Total
		NASA	Commercial	
1977	\$ 814	\$ 1,056	NA	\$ 1,870
1978	1,006	1,318	NA	2,324
1979	1,105	1,434	NA	2,539
1980	1,461	1,588	\$ 434	3,483
1981	1,736	1,785	335	3,856
1982	2,606	1,773	370	4,749
1983	2,527	1,558	878	4,963

(Note: NASA sales prior to 1980 include commercial sales.)
NA = Not available.

Source: 47.

NASA, and the Department of Defense. Currently, the DOD is the largest customer, followed by NASA and commercial customers (see Table VIII). (Note that these sales figures differ from the figures for space program expenditures in Table I. This is because program expenditures include all program costs, not just purchases of space systems.) The DOD has the widest range of uses for spacecraft, including surveillance, meteorology, navigation, communications, and research. NASA is the primary sponsor of research programs, but these only accounted for 6 payloads between 1978 and 1984. Its operational missions have been limited to meteorology, communications, and remote sensing. Until recently, commercial uses were limited to communications, but NASA and a number of private firms are attempting to expand the realm of commercial activities in space.

In fact, space commercialization is on a par with SDI as

the hottest space topic today. In addition to satellite communications, four areas are seen as potential fields for commercialization: remote sensing, launch vehicles, upper stages, and space manufacturing (77). President Reagan has expressed a desire to turn over operation of the LANDSAT remote sensing satellite system to private industry, and if this is done, it has been forecasted that this market will reach \$2 billion annually by the year 2000. At least one company is trying to develop a launch vehicle to compete with the Space Shuttle and foreign boosters like the Ariane. Several companies have been formed in the last two years to market small upper stages for scientific and commercial payloads. Finally, pharmaceutical and pure materials manufacturers have been working with space companies to develop processing payloads to ride on the Space Shuttle and take advantage of weightlessness and other conditions of space.

Seller Concentration. The possession of monopoly power is a major concern of industrial analysis, and seller concentration is the structural dimension most closely related to this (118:56). A great deal of discussion has been devoted to determining the most appropriate way to measure concentration. Hall and Tideman assert that measures of concentration should have the following properties (77:163-164):

1. Be one-dimensional--that is, they should allow comparisons between industries on a single level.
2. Be independent of the size of the whole industry.
3. Directly reflect moves between industry members (e.g., increase when moving from a smaller firm to a larger firm).
4. Be cardinal. If every firm were to be split evenly into two smaller firms, the measure would decrease by

- half.
5. Be a decreasing function of the number of firms.
 6. Range from 0 to 1 (for ease of use).

The concentration measures most often used in industrial analysis are concentration ratio and the Herfindahl-Hirschmann index. These are static measures, which describe the industry at one time, rather than dynamic measures, which reflect changes over an interval. The concentration ratio is the percentage of the total industry size contributed by the n -largest firms, where n is usually 4, 8, or 20. It violates properties 2 and 3, but is calculated in this study because it is the most commonly-used measure (77:165). The Herfindahl-Hirschmann index is defined as:

$$H = \sum_{i=1}^n s_i^2$$

where s_i is the market share of the i th firm, with n the number of firms in the industry. H is also calculated when possible since it avoids the shortcomings of the concentration ratio by including all firms (78:165).

Concentration ratio is usually defined on the basis of total industry sales, capacity, employment, shipments, or value-added by manufacturing (118:56). The Bureau of the Census reports concentration ratios based on value of shipments, employees, production workers, and value added to the 5-digit SIC level. The industry definitions used by the Census have been frequently criticized in the economic literature, but the concentration measures derived with them at least provide a rough benchmark of concentration in the industry as defined in this study.

Table IX.

Concentration Ratios for Space and Missiles Industries.

SIC	Description	Year	C4	C8
19252	Space Vehicle Systems	1967	.85	.99
37612		1972	.93	D
		1977	.91	D
19254	R & D on Complete Space Vehicles	1967	.82	.93
37614		1972	.85	.97
		1977	D	.99
1925	Guided Missiles and Space	1967	.60	.85
3761		1972	.62	.88
		1977	.65	.93
3764	Space Propulsion Units	1972	.59	.92
		1977	.69	.93
3769	Space Vehicle Equipment	1972	.70	.85
		1977	.76	.86

Sources: 44; 45; 46.

The concentration ratios for the top four and top eight firms in the space and missiles industries for the years 1967, 1972, and 1977 are listed in Table IX. The space vehicle systems industry (SIC 37612) is the most highly concentrated of the group. The concentration ratios show a trend towards increasing concentration in the spacecraft industry. This reflects the decrease in the number of firms active in the industry between 1967 and 1977 (from 18 to 13). The relatively lower concentration ratios for the overall space and missiles industry (3761) and the space propulsion industry (3764) can in part be accounted for by the fact that "Guided Missiles" and "Space Propulsion" include non-space products like tactical missiles and their propulsion units, which are

smaller and less complex than space systems, with a larger, worldwide market among military forces.

The Census figures seem rather high when compared with other estimates of market shares. Studies by Frost & Sullivan, a market research firm, indicated that the top five firms in the FY 1984 SDI market accounted for 46% of sales, while the top five firms in the space reconnaissance and surveillance market held almost 60% of the market in FY 1984 (66: 130). Both of these markets are subsets of the spacecraft industry (37612), and would be expected to exhibit higher, not lower concentration ratios.

Using data obtained from the Acquisition Management Information System (AMIS), a database of all current Air Force Systems Command acquisition contracts, this author found that the top four firms in the space vehicle industry accounted for 72% of dollars awarded by Space Division on contracts for complete space vehicles, the top eight, 93% (1). The Herfindahl-Hirschmann index for the firms in this sample is 0.1183. Taking the inverse of this number obtains the number of firms in the industry if all firms were of equal size-- 8.45, or between 8 and 9 firms (77:105). If this were true, the C4 ratio would be 0.473, indicating an industry with moderately high concentration. Like the SDI and reconnaissance markets, the Space Division sample represents a major subset of the total spacecraft, and would be expected to exhibit higher, not lower, concentration.

The difference between the concentration ratios reported

by the Census and those obtained from these samples can be attributed in large part to how the Census assigns plants to an industry. The Census categorizes plants according to the primary product produced in the plant, as determined by value of shipments. With this method, some plants involved in the production of spacecraft would be excluded from the sample. For example, the primary SIC for Rockwell's Space Systems Division, a facility in Seal Beach, CA which produces the GPS satellite--the largest current DOD satellite program--is identified as 3662, Radio and TV Communications Equipment (134). The primary SIC for RCA's Astro-Electronics Division in Princeton, NJ, which is one of the "Big Three" manufacturers of commercial communications satellites, is also 3662 (134). The SIC for the Lockheed Missiles and Space Company facility in Sunnyvale, CA, is 37611, Guided Missile Systems, because its primary product is the Navy's Trident missile. Excluding these plants, each of which represents a significant share of total spacecraft production, from the Census sample would possibly drive the resulting concentration ratio higher than what may actually be observed in the industry.

Nevertheless, it is safe to say that the space vehicle industry is highly concentrated. Still, industries with C4 ratios above 0.60 are considered tight oligopolies, especially when characterized by high entry barriers and a tendency towards cooperation (120:616). Such structural features are typically associated with excess profits and other performance

results. However, as will be shown, the evidence on performance indicates this has not been the case in the spacecraft industry.

Buyer Concentration. As stated earlier, there are three customers for space vehicles: DOD, NASA, and satellite communications companies. The DOD's share of the space budget surpassed NASA's in 1982. Even before then, the DOD was perhaps the most influential customer in the market, through its extensive R & D programs, which benefited the industry both directly through contracts and indirectly through the commercial applications of technology developed under these contracts:

The United States is the only country (except the USSR) where the powerful drivers of large military R & D budgets serve to accelerate the advance of space technology. Elsewhere, the lack of military space programs is loudly resented by the industry [31:1186].

This is not to say that there have not been similar benefits from NASA programs. In many cases, though, the technology used in NASA programs--the LANDSAT remote sensing satellite, the GOES meteorological satellite, and the TDRSS tracking and data relay satellite, for example--was first developed for military systems.

NASA's influence in the industry also differs from DOD's because it tends to have a smaller number of on-going programs, a few of which are extremely large. This means its contracts are concentrated more tightly than DOD's (117:341). In FY 1982, for example, the top 4 NASA contractors accounted for 45% of the dollars awarded, compared to 16.6% for the top 4

DOD contractors (42; 8:159).

The commercial market is the newest and smallest set of customers. At present, the market is limited to communications satellites. The customers include both domestic long-distance communications networks such as Western Union, AT&T, Satellite Business Systems, and American Satellite and international consortiums such as Comsat, Intelsat, Telesat Canada, Permutel, and Inmarsat. The commercial market is growing at about the same rate as the DOD, and it is expected to surpass NASA and become the equal of the DOD by the year 2000, due to the expansion of commercial activities into other uses of space (77). At the present, however, the major buyers are, in order of size, the DOD, NASA, and commercial communications firms. Thus, in the DOD market, the buyer concentration is 1.0.

Conditions of Demand and the Nature of the Product. The demand for space vehicles reflects the characteristics of the customers described above. NASA's demand is most clearly irregular, rising with major, highly visible programs like Gemini, Apollo, Skylab, and the Space Shuttle, and falling in between years. The impact of major programs is accentuated by the fact that NASA prime contracts tend to be few, large, and highly concentrated in their distribution. Because the DOD has the most extensive operational programs, the cycles of individual programs--rising with development and the award of the production contract and falling as the satellites are launched and placed into operation--are somewhat dampened by

overlaps among programs. One system may come up for development competition as another completes its production run. Although the commercial market is relatively new, its demand behavior will reflect the demand for its own products--long-haul communications, pharmaceuticals, remote sensing data, and pure materials. The number of users and the variety of their needs will in all likelihood make this the most stable of the three markets in the long run.

The cyclical nature of demand is combined with the limited extent of the market for space systems in terms of the number of units needed. Between 1958 and 1983, successful U.S. space launches totaled 822 (49:583). During the period 1978-1983, the annual launch rate averaged less than 20. Although launches often carry more than one payload, the total number of space vehicles launched remains low.

Until the recent award of a contract for 28 Global Positioning System (GPS) satellites to Rockwell, the largest number of satellites produced for a program was 16, for the Defense Satellite Communications System (DSCS) II program. Even this number is misleading, since the initially contracted number was 6 (3). Virtually all scientific satellites are built in lots of 3 or less, and most commercial buys are for 2 to 6 spacecraft. The small size of most orders is due to the high cost of spacecraft, which stems from the nature of the product itself.

Because spacecraft, unlike any other products made on Earth, do not operate on this planet, they have characteristics

unlike other terrestrial products. They must survive launch on a rocket, which subjects them to stresses 8 to 12 times the force of gravity on Earth and to supersonic acoustic shocks. On orbit, they operate in an environment much different from Earth's. Unprotected by the atmosphere, they encounter temperatures ranging from near absolute zero to hundreds of degrees Centigrade. They are constantly bombarded by cosmic rays, solar proton emissions, infrared and ultraviolet radiation, and micrometeorite particles. They exist weightless, in a high vacuum. And until the development of the Space Shuttle, they were inaccessible for inspection, repair, or resupply. Even with the Shuttle, the cost of a repair mission is on the order of \$50 million.

This environment creates a whole set of engineering challenges. The tremendous energy required to accelerate an object to the velocity where it can escape from the Earth, spacecraft must be launched on rockets which are themselves engineering achievements--5% structure and 95% fuel. The lift capacities of launch vehicles limits the weight of satellites--the maximum load that can be boosted to geosynchronous orbit, for example, is 3,100 kgs. The structure of the spacecraft must be strong enough to survive the shock of launch, but not so heavy as to exceed the booster's weight limit, or even to encroach upon the weight available for power, communications, guidance, and other systems. The less weight taken up by the structure, the more that can be used for other functions like the payload. Thus, there has been substantial research into

and application of composite materials in spacecraft, reducing the weight of structures from around 14% of total weight in 1960s spacecraft to less than 5% in current vehicles (17:19).

The thermal, radiation, and vacuum conditions of space force systems to meet exacting specifications. The side of the spacecraft facing the sun generates very high temperatures at the same time that the shaded side experiences extreme cold. The thermal protection design must shield against this range of temperatures, while giving off the excess heat generated by the equipment inside, and balancing the temperature flux between the hot and cold sides. The shielding must prevent solar radiation from penetrating and destroying the electronic circuitry. In a hard vacuum, the boundary layer of gasses on a surface are released, and metals touching each other tend to weld together.

Other systems on a satellite must also carry out sophisticated tasks automatically. The guidance and control system on a spacecraft must be able to compute its present position, velocity, and attitude, compute the deviations from the desired orbit and attitude, and instruct the propulsion and/or stabilization system to correct the deviations. For satellites with communications, navigation, or surveillance or other sensor systems, the satellite must also provide a stable platform not subject to the loads produced by other parts of the spacecraft. The power system must generate all electricity needs, as well as insure adequate reserves are stored in batteries when operating in the Earth's shadow. The satellite

must be able to respond to communications from Earth, report the health and status of all systems, receive, store, and execute commands, and download data collected by the payload.

The costs of low production runs are increased by the tendency to redesign units based on the on-orbit performance of preceding ones. Modifications are made to correct faults found in earlier units after launch. The result is that even within a single series of satellites each one may be different in its design. Because of the complexity and low number of satellites, non-recurring costs like prototype development represent a large share of the total unit cost of a satellite.

Taken together, these considerations make spacecraft very expensive items. The DSCS III (Defense Satellite Communications System) satellite, for example, cost \$145 million per production model unit (127:80). The Intelsat V commercial communications satellite cost \$86 million per unit (127:64). In comparison, an F-15 fighter plane costs approximately \$30 million, a B-1B bomber over \$300 million. Added to the cost of the spacecraft itself is the cost of the launch vehicle, the booster stage, if operating in other than low orbit, and the ground support equipment and personnel to track, command, and control the satellite, which can be much more than the cost of the satellite itself (3).

Because satellites are costly to build and launch, produced in small numbers, and intended to operate in the harsh environment of space, a fair amount of the cost of production is the validation of the design through very

Table X.

Spacecraft Qualification and Acceptance Tests.

Electrical systems performance
Radio frequency antenna range
Radio frequency interference
Antenna boresight alignment
Thermal balance
Thermal vacuum
Pressurization and leak check
Solar array deployment
Solar panel illumination
Mass properties/spin balance
Acoustics
Pyrotechnical shock
Sinusoidal vibrations
Power system end-to-end test

Source: 41:70.

very extensive reliability tests (17:20; 41). Satellites are designed to the highest degree of reliability of any man-made systems. Every single part on the satellite must be tested to confirm it will withstand the stresses of launch and operate properly in space. Computer-aided design (CAD) and computer-aided manufacture (CAM) are heavily used to build in high reliability. Subsystems supplied by subcontractors must meet rigid specifications, and rigorous quality assurance program administered by the prime contractor oversees their production, test, and inspection (41:65). Once delivered, these components and subsystems are tested individually, then assembled with the spacecraft, and both subsystems and the complete spacecraft are subjected to a battery of verification tests. Typical qualification and acceptance tests for a spacecraft are listed in Table X. These tests create conditions well beyond those anticipated in routine launch and

on-orbit operations, and commonly take as long as the actual assembly of the spacecraft. The tests require dedicated facilities, including computers to simulate electrical inputs and measure responses, thermal chambers to test performance and thermal balance in the extreme temperature conditions of space, antenna ranges where the vehicle's receivers and transmitters are calibrated, software labs where control and diagnostic routines are validated, acoustic chambers where the craft is subjected to the sonic stresses of launch, and vibration stands to check its ability to withstand the mechanical stresses of launch.

The process of building a spacecraft is a lengthy one. Figure 2 shows the timeline of a typical spacecraft program from contract award to launch. As can be seen, the design and development process is longer than the production process, and the systems test process about as long as the actual assembly of the spacecraft. Figure 3 details the systems test timeline for a typical program. These timelines are essentially equivalent for both military and commercial spacecraft (127:34-36). In addition, the tests required by military and commercial customers are largely the same (127:12-13).

The extent of the overall market for spacecraft, then, is limited, and demand within this market tends to be irregular. The nature of the product is such that order sizes are small, with a very strong emphasis on reliability and testing, as well as changes in design between individual spacecraft in the same order.

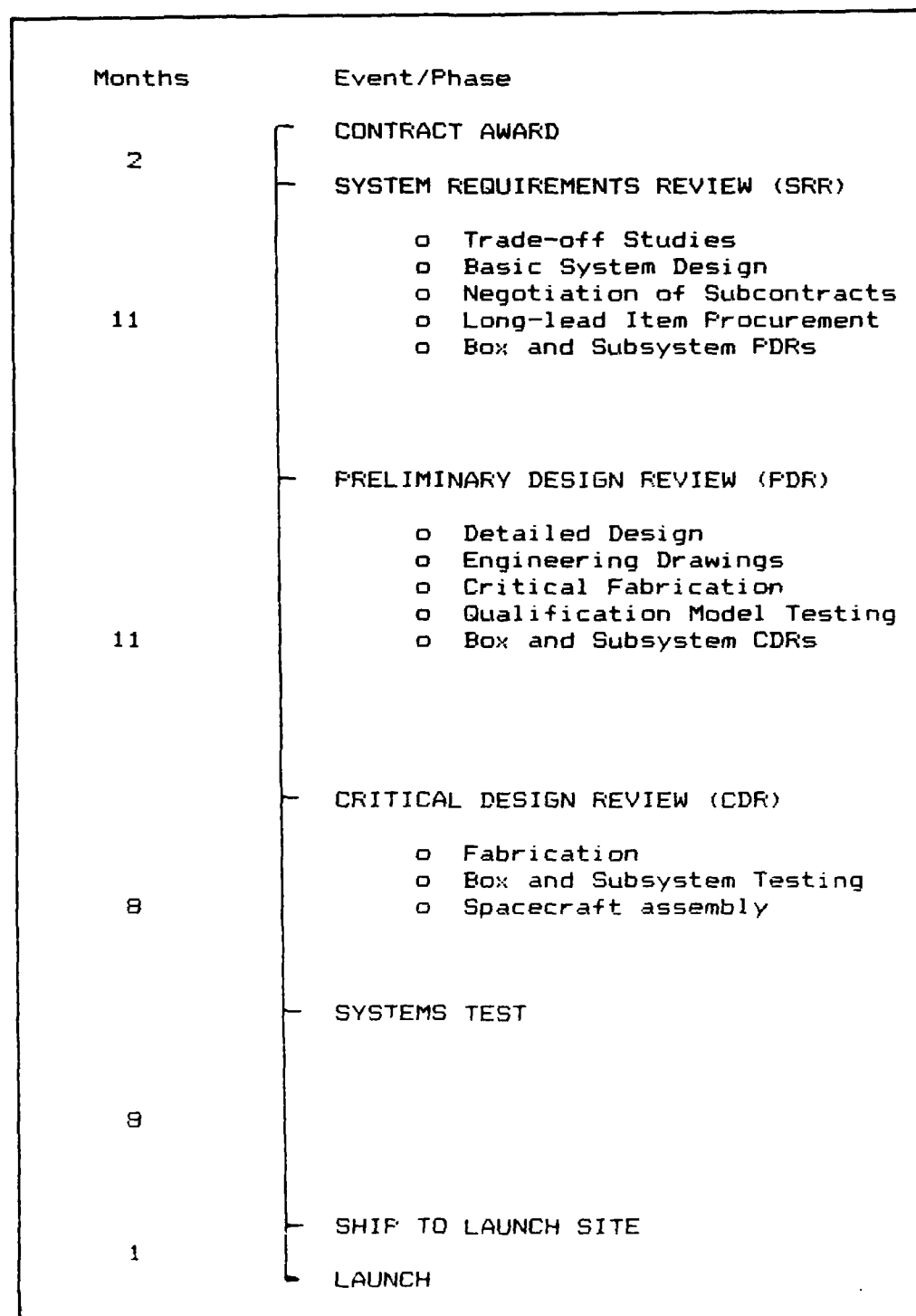


Figure 2. Timeline for a Typical Spacecraft Program (33).

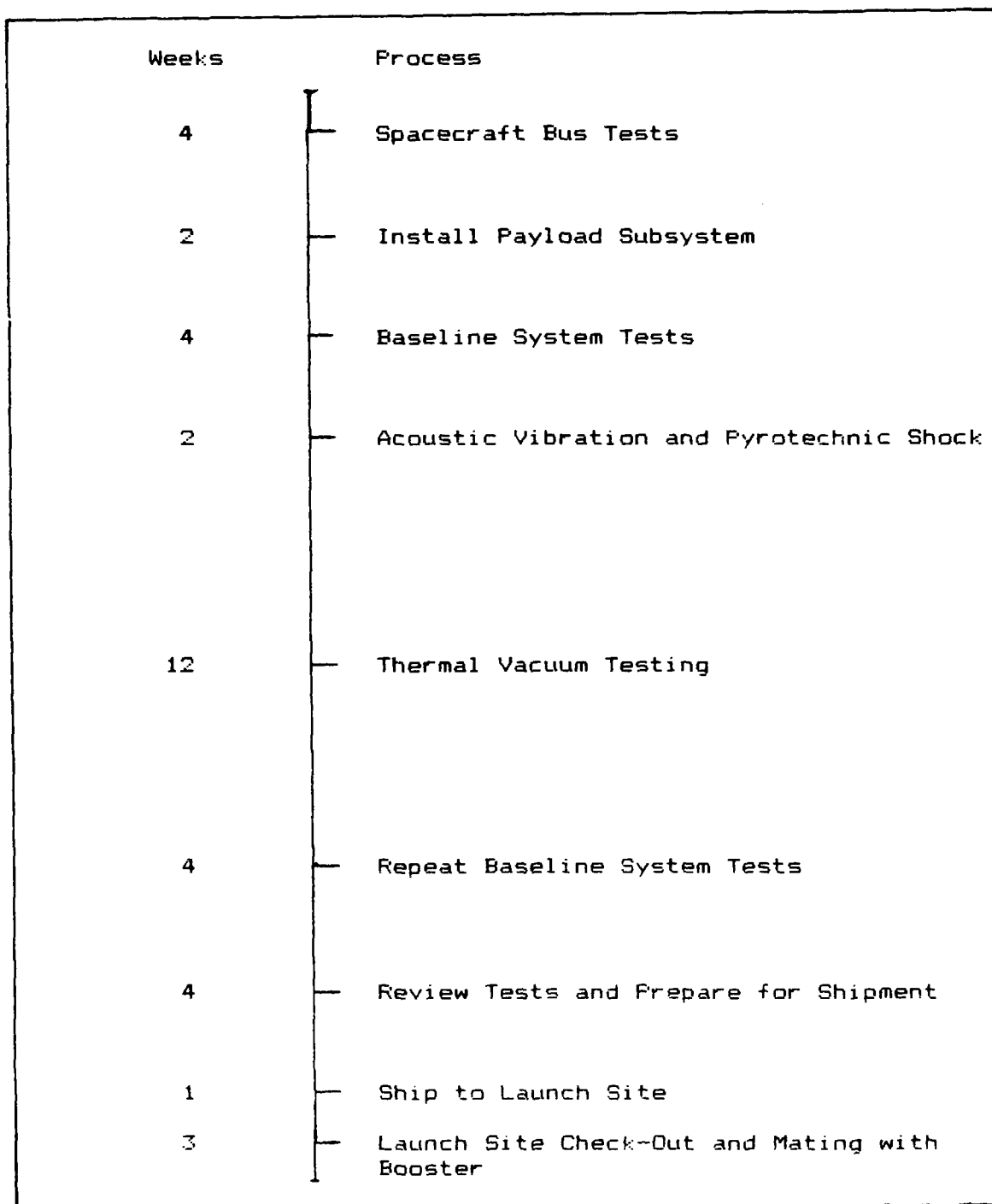


Figure 3. Systems Testing Timeline for a Typical Spacecraft (33).

Conditions of Supply and Production Technology. The basic inputs to an industry are labor and materials, which come together through technology in production facilities to produce a finished product. In the case of the space vehicle industry, the characteristics of the product described above are reflected in the costs facing producers.

The technical sophistication of space vehicles creates a need for large numbers of scientists and engineers. Indeed, it was the launch of Sputnik that created the impression of a scientific education gap between the US and the USSR, prompting huge increases in enrollment and funding for engineering and other technical programs (97:160-2). Production workers constituted only 31% of the total missiles and space workforce in 1984, compared to 47% of the avionics and airframes workforce and 48.5% for the overall aerospace industry (8:144-5).

This clearly indicates the space industry workforce is predominantly white-collar, with the majority of employees engaged in scientific, engineering, management, and administrative duties rather than in production itself. Of the 9,542 employees involved in satellite design, testing, and manufacturing at Hughes, for example, over 45% are engineers, compared to production workers, who represent 28.5% of the total (150). The ratio of engineers and scientists to production workers in Lockheed's Space Systems Division was four to one (24). A recent Government Accounting Office (GAO) study of employee compensation by 12 aerospace contractors found that an average of 58% of total payrolls went to profes-

sional pay, 15% to clerical, and 27% to factory pay (71:3).

Raw materials represent a small percentage of the cost of materials--less than 2% in 1982, compared to over 77% for electronic and other components and assembled electronic subsystems (47:16-17). The increased use of composites to save weight will further decrease the use of aluminum, steel, nickel, titanium, and other metals. The demand for electronic parts and systems is not unique to space vehicle production--the aerospace industry first began to notice the importance of this technology in the early stages of the guided missile programs in the mid-1950s, and quickly began to integrate upstream (136:83-95). Many of the companies in the space vehicle industry are, in fact, major electronics producers.

The performance requirements of spacecraft, however, translate into specifications for components considerably different from those for terrestrial products (3). As described earlier, every component and subsystem on a spacecraft must be tested both individually and as part of the assembled spacecraft, in addition to the standard quality assurance checks. Because production runs are small, however, suppliers are often unable to reach an economical lot size. As a result, Aerospace Corporation cost studies have found, the unit cost of a space-qualified component supplied to a prime contractor is higher than the unit cost of a comparable component for other military or commercial uses (3; 5:20 Apr 84).

In addition, the technical requirements for space systems are often at or ahead of the state of the art (127:10-12).

Thus, prime contractors may be forced to subcontract out for key components based less on the economics of make-or-buy than on the fact that their scientific and engineering personnel have no expertise in a particular technology. In other cases, the demand for a particular type of component is so small that there is only one source.

The subsystem suppliers are often other members of the industry. Hughes, for example, is currently the only domestic source of travelling-wave-tube amplifiers (TWTAs), an essential element of all communications satellites. Two former TWTA manufacturers, Varian and Watkins-Johnson, ceased making space-qualified TWTAs in the early seventies because they felt the extent of the market was too small for an acceptable return on their investment (23:37-40).

As the interaction matrix in Figure 4 shows, virtually every member of the industry has had subcontracting relationships with the other members. This indicates that few, if any, firms are capable of manufacturing entire space vehicles themselves. Instead, economic and technical considerations force them to contract out numerous subsystems. Rockwell, the GPS primecontractor, for example, has over 30 subcontractors, who provide such items as propellant tanks, thrusters, the orbit injection subsystem, antenna transponders, thermocontrols, electronic filters, and solar arrays (123).

Firms have begun to involve subcontractors at the initial stages of competition now, by forming coalitions to bid on programs. The bidders responding to NASA's Space Station

	X	X	X	X		X	X	X			X	Ball
X	X		X	X	X	X		X	X	X		Boeing
X	X	X		X		X	X	X				Fairchild
X	X			X	X	X		X	X			Ford
	X		X	X	X			X				General Dynamics
X	X		X	X	X	X	X					General Electric
	X		X	X	X							Grumman
X	X	X	X	X	X							Hughes
X	X	X	X									Lockheed
X	X											Martin Marietta
	X											McDonnell-Douglas
X	X											RCA
X												Rockwell
TRW												

(An X indicates a subcontracting relationship between firms.)

Figure 4. Subcontracting Relationships Among Space Vehicle Manufacturers (derived from 5, 55, 131).

requests for proposals were all multi-firm teams, ranging in size from 4 to 25 members (55). During the Milstar concept validation phase, competitors included teams of Boeing and Ford Aerospace, TRW, Hughes, and RCA, and Lockheed, Martin-Marietta, and McDonnell-Douglas (119). This approach allows the prime to share the cost of proposal development with its subcontractors, and reduces integration problems in the production phase by establishing a common understanding of the system design from the earliest stage.

The facilities used to design, build, and test space

vehicles reflect the importance of reliability, and have evolved as the size and complexity of these systems increased. As mentioned earlier, manufacturers have often had to rebuild or add to these facilities as designs changed and spacecraft became too big, too heavy, or too complicated. RCA, for example, recently completed a 46'x46' thermal vacuum chamber to accommodate the larger spacecraft made possible by the size of the Space Shuttle payload bay, along with a K-band antenna range to test new antenna systems (17:20).

Barriers to Entry and Strategic Groups. Bain defines the condition of entry as "the disadvantage of potential entrant firms as compared to established firms" (19:252). An outside firm which acquires the plants and assets of an industry member--such as General Motors, which recently bought Hughes--is not considered an entrant unless it adds to production capacity. "Mere change of ownership . . . does not constitute new entry" (19:252).

There are three types of barriers to entry: economies of scale, product differentiation, and absolute cost advantages. The first is not yet significant in the space vehicle industry. Production runs are still low and designs vary greatly between programs. But manufacturers are becoming attuned to the efficiencies of production where feasible, as in the comsat market, where Hughes, Ford, and RCA all offer standardized spacecraft designs to reduce the cost of design changes between systems, and the scientific and space industrialization market, where Fairchild has developed a Multi-Mission Spacecraft (MMS)

design to incorporate a variety of payloads (58).

Product differentiation is largely a matter of brand loyalty. When the buyer initiates the development of the product, as in the case of the space vehicle industry, where customers request from manufacturers proposals for satisfying a set of requirements, the designs offered are evaluated more on their own merits than on the reputation of the offeror. In fact, in government source selections, all company identifiers are removed from proposals before evaluation.

To effectively compete for a spacecraft contract, a firm must first of all demonstrate its ability to meet the technical and management demands of designing, building, and testing a spacecraft. This requires the firm possess an extensive research and development base. The firm seeking to enter the market must possess the capability to exploit a price or design opportunity, and to withstand a possible reaction by the dominant firms to new competition. Clearly, certain firms like Hughes and Lockheed possess a substantial base of knowledge in their particular spacecraft technology specialties, and must certainly influence the decision of other firms to compete for such contracts.

The decisions as to which contracts to bid on is a reflection of the firm's competitive strategy--a combination of the ends the firm is striving for and the means by which it seeks to achieve them (110:xvi). The process by which a firm develops its competitive strategy includes identifying its present situation, analyzing the factors of the industry, its

competitors, and governmental influences, evaluating alternative moves against these factors, and choosing that alternative that best directs the firm towards its goals within this market context (110:xix-xx). In the context of the spacecraft market, the strategic choices of primary interest are which systems a firm picks to compete for and which markets the firm chooses to compete in.

By looking at how each firm chooses to compete in the spacecraft industry, it is possible to identify "strategic groups": that is, groups of firms following strategies that are similar in key ways (110:129). The composition and character of these groups affects the level of rivalry within the industry, including competition for contracts. In the spacecraft industry, strategic groups can be characterized primarily by their specialization and their choice of markets.

If one looks at the list of systems a firm has produced over the time it has been in the industry and compares it with another's list, trends towards specialization in one or two types of systems can be seen. Table XI lists major military and civilian space systems produced by each firm over the last twenty-five years. A tendency on the part of most firms to specialize is apparent. With Apollo, the Space Shuttle, and GPS, Rockwell has established itself as the expert at deploying large-scale space systems. Ball has limited itself to small scientific satellites. The areas in which a firm specializes stem mostly from what programs the firm worked on in the early stages of the industry. Hughes' expertise in spin-stabilized

Table XI.

Major Systems Produced By Firm.

Ball	Boeing
CRRES (scientific)	Mariner
ERBS (scientific)	SAGE (scientific)
IRAS (scientific)	Inertial Upper Stage (IUS)
P-78-1 (scientific)	
General Electric	Ford Aerospace
Nimbus (remote sensing)	IDSCP (communications)
LANDSAT (remote sensing)	Insat (comm & weather)
UARS (remote sensing)	NATO III (comm)
DSCS III (comm)	Intelsat V (comm)
Hughes	General Dynamics
GOES (weather)	Centaur (upper stage)
Intelsat IV (comm)	ARAS (scientific)
Anik C (comm)	
Galaxy (comm)	Lockheed
Palapa (comm)	SAMOS (surveillance)
SBS (comm)	MIDAS (surveillance)
Telstar (comm)	MILSTAR (comm)
Westar (comm)	Teal Ruby (scientific)
Leasat (comm)	Space telescope (scientific)
McDonnell-Douglas	Martin Marietta
PAM-D (upper stage)	SCATHA (scientific)
Skylab (manned)	Transtage (upper stage)
Gemini (manned)	Viking (scientific)
Rockwell	RCA
Apollo (manned)	Amersat (comm)
Space Shuttle Orbiter	Anik B (comm)
GPS (navigation)	Gstar (comm)
	Satcom (comm)
TRW	Spacenet (comm)
DSCS II (comm)	DMSF (weather)
Fltsatcom (comm)	Tiros (weather)
TDRS (data relay)	Transit (navigation)
DSP (surveillance)	
Vela (surveillance)	

Source: 142.

geosynchronous communications satellites, for example, is the result of its having built the first such satellite, Syncom, for NASA in the early 1960s.

Specialization in the spacecraft industry thus affects the market sectors in which a firm competes. The commercial market is currently limited to communications satellites, and is dominated by the major comsat producers--Ford Aerospace, Hughes, and RCA--referred to as the "Big Three" by the aerospace industry press (30). The Big Three have been able to exploit their expertise in comsat technology only because they have also been able to adapt to the perspective of commercial customers (30). Unlike government contracts, commercial space contracts often require the producer to get involved in financing the purchase (127:v). In addition, commercial customers are less interested in advanced technology than in cost-effective performance, and their contracts are now almost exclusively fixed-price agreements (127:v).

At the other end of the spectrum from the Big Three is Ball, which has the smallest market share and has only built small scientific satellites for NASA and the DOD. Also somewhat in the same position as Ball is Fairchild, which has been unsuccessful so far in its attempts to establish itself in the commercial market (5:16 Sept 85). Lacking the financial resources and substantial technical resources of larger producers, they have concentrated on research spacecraft programs, which present fewer risks due to their smaller size and scope and their reliance on cost-plus contracts.

In between are those firms usually considered the core of the defense industry--firms like Lockheed, General Dynamics, and McDonnell-Douglas. Like these firms' other operations, their space systems divisions are primarily involved in working on government contracts. Looking to maintain or expand their market shares, they often find themselves competing for the same contracts. Unlike the Big Three, they have preferred the customer-arranged financing of NASA and DOD contracts to the cooperative ventures found in the commercial market (30). Indeed, one firm has cited the problems of marketing and financing arrangements as its main reasons for staying out of the commercial market (124).

The firms in this middle group tend to be less specialized than those in the other groups. Although they recognize the limitations of their expertise, they have often overcome their technical disadvantages in competition for particular programs by simply subcontracting out those systems they cannot provide themselves. The most striking example of this behavior is the Milstar program, a survivable strategic and tactical communications satellite system. Lockheed beat out TRW for the \$1.05 billion development and prototype production contract. Lockheed, however, has little expertise in communications subsystem, and soon after winning the contract, it negotiated with TRW to build the communications payload (119:42). Hughes and RCA are also developing subsystems for Milstar.

The primary barrier to entry into the industry, then, is one of absolute cost--the cost of acquiring and maintaining the

corps of scientific and engineering skills and the set of production and test facilities required to build a space vehicle--which is compounded by the limited extent of the market. Within the industry, firms face financial and technological obstacles which influence how, and in which markets, they choose to compete.

The DOD Market. Since Chapter Four focuses on conduct and performance of the industry in the DOD market, the last topic to examine is the unique structural aspects of this market. There is an extensive literature on the defense market, which generally agrees on its key structural characteristics (2; 68; 108; 140). The most obvious feature of the DOD space vehicle market structure is that there is only one buyer--the DOD, whose purchasing agency is the Space Division (SD) of the Air Force Systems Command, headquartered in Los Angeles, CA. As the sole buyer, Space Division is the predominant influence in the market. As mentioned earlier, the degree of seller concentration appears to be less in the Space Division market than in the space vehicle industry as a whole. This is at least in part due to the fact that the DOD has a larger number and wider variety of programs than NASA, and more diverse requirements than commercial customers.

The DOD is also distinguished by its method of procurement. The process through which the DOD acquires its major systems is outlined in the next chapter. For the purpose of this discussion, it is sufficient to mention three aspects of the process which affect market structure.

First, until the final phase--production and deployment, there is no durable good, aside from prototypes, produced. In each of the three preceding phases--concept exploration, demonstration and validation, and full-scale development, the DOD issues requests for proposals to which bidders reply with studies and design proposals. These proposals are evaluated on a number of factors, including technical competence, performance parameters, ability to produce, and cost. Thus, the selection of source of supply depends on much more than price alone. Indeed, Peck and Scherer, in their study of the major systems acquisition process, found that design, contractor capability, past performance, and industry planning considerations played at least as much of a role as cost (108:361-385).

Second, the life-cycle of major systems are on the order of 10 to 20 years. Of course, the process of replacing a system are underway well before it becomes obsolete; even so, production contracts for particular systems may be offered only every 5 to 10 years. As the cost of systems has been rising faster than the defense budget, this has meant that production contracts are fewer, bigger, and less frequent (85:31-32).

Finally, this process is characterized by an extensive management and oversight system. Before each phase of the process begin, reviews are conducted at the Space Division, Systems Command, Air Force headquarters, and DOD levels (DOD). These review authorities, combined with the Space Division program office staff and Air Force Plant Representative Office

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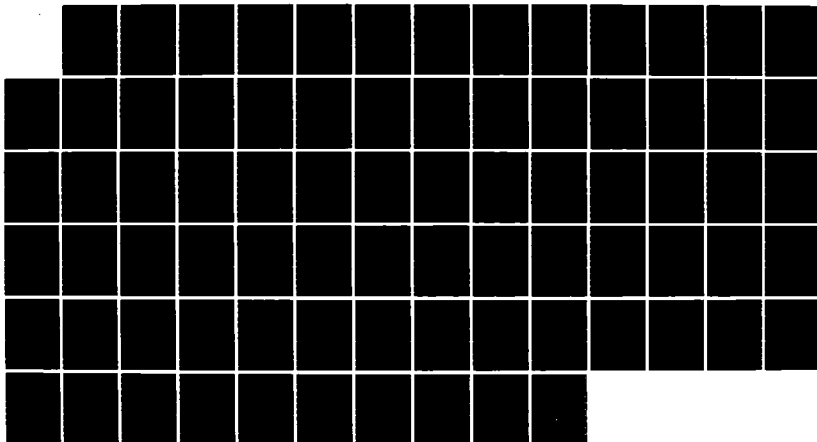
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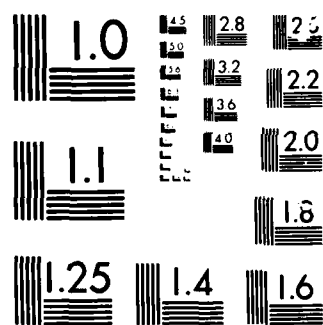
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(AFPRO) personnel, introduce significant management overhead costs for contractors (3).

These characteristics of this market add to the barriers to entry identified above by favoring those firms with a history of experience in DOD space systems, significant R & D resources, and familiarity with the DOD acquisition process.

Conclusion

In summary, the space vehicle industry is oligopolistic, and faces a monopsonistic buyer in the DOD market. The nature of the product--its technical complexity, high cost, and extremely high reliability--influences many of the conditions of demand and supply. These features, added to the small size of most spacecraft order, results in a situation in which prime contractors have to subcontract out, often to other industry members, without much leverage in determining price. The absolute cost of having the capacity to develop and build spacecraft, when compared to the extent of the market for such products, presents the most significant barrier to entry.

The implications for competition are not clear. Adams and Adams contend that from a purely structural standpoint, a monopsony-oligopoly market does not supply a benchmark for cost performance, and any potential monopsony power can be neutralized by networking among industry members (2:281-2). On the other hand, Scherer suggests that:

A virtual infinity of potential design feature combinations is open to bidders, and each firm's judgment concerning the quality-cost-time tradeoffs most likely to win approval from the customer . . . invariably differs from that of its rivals [118:201].

Kaldor also finds that there is "intense competition between the major contractors to obtain future contracts" (85:27). The basis of this competition, the behavior of sellers in responding to it, and how the space vehicle market has performed are examined in the next chapter.

IV. Conduct and Performance of the Market

This chapter examines the conduct of the military space market--the process of acquiring space systems for defense needs and how firms respond to this demand--and its performance--the outcomes of the market in terms of efficiency, equity, and social welfare. It begins with a general description of the major systems acquisition process, then looks at the particular example of space systems. The process is then examined from the seller's point of view, in terms of how competition for contracts is determined by the strategic groups in the industry. The discussion of performance begins with a look at the appropriate measures of market performance. It then examines the dynamic and internal efficiency of the market, and evaluates profitability and risk-bearing in terms of allocative efficiency and equity.

Conduct

Bain defines market conduct as "the patterns of behavior that enterprises follow in adapting or adjusting to the markets in which they sell" (19:9). Peck and Scherer have suggested that a contracting system, rather than a market system, is the appropriate commercial equivalent to the major systems acquisition process (108:55-61). A contracting system differs from a simple market model in that the buyer and seller agree to the terms of the purchase before the product exists (108:61). The contract may clearly specify the product or

service to be provided, or it may cover tasks whose results cannot be foreseen in detail in advance.

Discussions of conduct in industrial organization texts tend to emphasize the price and production behaviors of firms and their competitors--how they determine what to produce, how to market, and how to price. In a contracting system, conduct is a matter of how the buyer and seller come together to make a contract--how the buyer solicits sellers, how sellers choose which solicitations to respond to and how to respond to them, how the two parties reach agreement on the terms of sale, and how the contract is carried out.

This section describes the conduct of the process of acquiring space systems for the DOD. This process is similar to that by which the DOD buys most of its major weapons and support systems. Rather than thoroughly analyzing the major system acquisition process, this discussion simply outlines the general process, and then treats the particulars of space system acquisition in more detail. It concludes by examining the process from the seller's point of view--how firms choose which contracts to compete for and the nature of competition for these contracts. Finally, it tries to set the conduct of DOD space system acquisitions into perspective by comparing it with the conduct of commercial space programs.

Major Systems Acquisition. The Secretary of Defense designates requirements as major systems acquisition programs based on the magnitude of the needs, the extent of interservice

involvement, and the development risk (50). In general, systems are major if their estimated RDT&E costs exceed \$200 million and/or production costs exceed \$1 billion. A system comprises more than just a weapon or spacecraft; it includes peculiar support equipment, facilities, training, technical documentation, spare parts, testing and evaluation, and initial operation and maintenance (96:4).

The major systems acquisition process includes (20):

1. Defining a need
2. Budgeting and financing
3. Soliciting and exploring alternative solutions
4. Conducting test demonstrations
5. Choosing what to procure
6. Selecting sources
7. Conducting price and cost analyses
8. Negotiating and awarding contracts
9. Administering contracts
10. Operational use and disposal

The basic guidelines for this process are outlined in DOD Directive 5000.1, "Major Systems Acquisitions" (50). A basic objective of the process is that "Effective design and price competition . . . shall be obtained to the maximum extent practicable to ensure that defense systems are cost-effective and are responsive to mission needs" (50:2).

The major systems acquisition process has distinct phases. Normally, these are concept exploration, demonstration and validation, full-scale development, and production and deployment (50:4). Prior to each phase, reviews are conducted at all levels, from the program office up to the Secretary of Defense, to evaluate the status of the program and determine if it should be advanced to the next phase, continued for further

study in its present phase, or cancelled (96:19). The top level review group is the Defense Systems Acquisition Review Council (DSARC), which normally considers programs at Milestones I and II--prior to the demonstration and validation and full-scale development phases (51:2). Along with the DOD councils, the General Accounting Office and Congressional committees evaluate these programs as their funding is submitted in the DOD budget.

Component services surface their requirements for new systems in Justifications for Major System New Starts (JMSNS), submitted to the Secretary of Defense with their Program Objectives Memorandum (POM) for the budget year. The objectives of a system acquisition program include a variety of factors, which frequently come into conflict (103:2-1):

1. Improved performance
2. Economic affordability
3. Technical advances
4. Risk reduction
5. Improved quality
6. Strengthening the industrial base
7. Socio-economic considerations (e.g., labor surplus markets, small businesses, minority firms)

If the program is approved in a Program Decision Memorandum (PDM), a Program Manager (PM) is appointed, and a System Program Office (SPO) organization is established. This marks the beginning of the concept exploration phase.

The SPO is the focal point for the management of the entire acquisition process for a system (96:4). The program manager is responsible for preparing, defending, and managing the program budget and schedule, for devising the acquisition

strategy, for the study, design, development, testing, production, and initial operation of the system, for assuring logistics support, and for selection, negotiation, and administration of contracts. The SPO organization includes program control, configuration management, engineering, logistics, procurement, production, testing, training, and operations experts to assist the PM in acquiring and fielding "a system that meets the approved mission need and achieves the established cost, schedule, readiness, and affordability objectives" (50:11). The SPO exists throughout the lifetime of the system to retirement.

One of the first steps in the concept exploration phase is the development of an acquisition strategy. This plan lays out how technical and contractual considerations are to be integrated to maintain competitive exploration of alternatives. It includes guidelines for trading off investment, schedule, and performance risks to avoid sole-source procurement. The primary goal of the acquisition strategy is to sustain the power of the DOD to influence price and other terms in its contract negotiations by maintaining the pressure of competition on the seller.

Much of the emphasis on increasing competition and reducing systems costs centers on options available in forming the acquisition strategy, such as fly-offs, dual sourcing, component break-out, economic order quantity (EOQ), and multi-year procurement (MYP). A flyoff involves developing two alternatives in parallel, with competition for the production

contract. Dual-sourcing continues competition through the production phase by contracting with two separate firms for the same system. A variation on this option is component break-out, in which the SPO deals directly with subcontractors, supplying subsystems they produce to the prime contractor as Government-furnished equipment (GFE). EDQ and MYP do not increase competition, but seek to reduce costs by allowing contractors to take advantage of efficient production runs and the financial security of a multi-year contract.

The first major contracts let are usually for systems design concept studies. These are solicited through a Request for Proposal (RFP) identifying mission need, operational environment, threat, schedule and cost goals, and performance objectives. Bidders then propose technical approaches, outlining design features and cost, schedule, and performance parameters. These study contracts are typically fixed-price, with a short period of performance--around a year. At the same time, cost-plus contracts may be awarded for research and development of specific subsystems or technologies.

Based on the results of the systems concept studies and technology development, the SPO determines the alternative(s) offering the best potential balance of performance, schedule, and cost (96:17). These alternatives are outlined in the System Concept Paper (SCP), which is submitted through service review channels to the DSARC and the Secretary of Defense for their decision. Approval of the SCP is Milestone I and marks

the beginning of demonstration and validation phase.

In this phase, the alternatives are examined in more detail, and the value and feasibility of the design are explored in depth (96:22-25). This is accomplished in studies, prototypes, or a combination of both. A primary aim is to reduce or isolate technical risks and economic uncertainties. The fly-off is currently the preferred approach to this phase because it provides more information for weighing the alternatives and keeps competition going longer in the acquisition process. For some very large or highly sophisticated systems, however, the costs of dual-sourcing--or even development of a single prototype--are prohibitive.

If approved by the DSARC, the system proceeds with full-scale development. This involves the design, fabrication, and testing of a pre-production prototype, along with preparation of the documentation, training, and support equipment. The main events in this phase are the preliminary and critical design reviews (PDR and CDR), in which the SFO and the contractor(s) examine the design in great detail, making changes and agreeing on the final system configuration. The CDR is the last formal chance to comment on the design before official commitment to accept it (96:26). The SFO conducts Initial Operational Test and Evaluation (IOT&E) on the development system model(s) to qualify and validate that it performs according to specifications, or to document defects.

The service Secretary has the authority to make the Milestone III decision to advance the program into production

and deployment, provided the cost and schedule thresholds established at Milestone II are met (96:29; 50:5). The actual contractual commitment to production is made at this point. Except in cases of dual-sourcing, the SPO has by now entered into a bilateral monopoly with the prime contractor. Any changes introduced into the schedule, design, or cost of the system must be negotiated on a sole-source basis. This situation, critics hold, fosters a degradation of all system attributes--time, cost, and performance (68:93).

Throughout this process, a considerable oversight structure monitors and influences its progress. The SPO is assisted in the administration of the contracts by Plant Representative Offices, which reside at a number of contractor facilities. In addition to the reviews described above, each program is scrutinized annually when it submits its budget request. Programs with "high visibility"--high costs, embarrassing cost or schedule overruns, or controversial requirements--are also subject to investigation by the Office of Management and Budget, the General Accounting Office, and House and Senate Committees. Although industry and DOD leaders criticize these layers of reviews, for most programs, they do not introduce significant changes to a program's schedule or funding (68:78-82; 108:451-60). What they do contribute, though, is a perception by many members of the industry that these oversight groups are "a constant source of disruption and interference" (5:2 Jul 84; 108:453).

Space Systems Acquisition. The process by which Space Division acquires space systems for the DOD differs only slightly from that described above. (Although this study concerns itself with the spacecraft market, it must be remembered that space systems, like other major systems, include more than just the satellites. The SD SPOs are also involved in the procurement of command and control equipment, upper stage boosters, and sometimes receivers, ground stations, or other user equipment.) Space programs have historically followed a four-phase process (103:2-8).

In the first phase, concept exploration, the initial proposals for the system are prepared. Once the JMSNS for a space system has been approved and a SPO formed, the SPO releases a Request for Proposal (RFP) for comprehensive system studies. Depending on the number of bids received and available funds, three to five firms are then awarded fixed-price contracts. These firms prepare system design proposals that integrate advanced development studies undertaken in R&D programs into an overall concept. Much of the SPO's work in this phase involves working out the specific requirements and preparing cost estimates.

These proposals are then evaluated and one or more are then selected to be developed in the next phase--concept validation. The proposals are considerably enhanced and refined, and substantial engineering effort is put into preparing a competitive package. The SPO takes a great deal of care to insure that information about rival designs do not pass

between competitors. The SPO holds preliminary design reviews to examine each design and make final comments regarding its specifications and requirements. Once the decision to proceed to full-scale development has been made and all comments have been exchanged between parties, the SPO issues an RFP for the full-scale development contract.

The bidders then submit their designs in the form of proposals. When the proposals have been received, the SPO holds a source selection board to choose the winning design. A cost-plus-incentive-fee contract is negotiated and awarded, and the prime contractor begins work on one or more development models of the spacecraft. Development models of ground support equipment and user systems are also built. The development models are launched and the entire space system is operationally tested. This phase may last from two to eight years. In most cases, the decision to go ahead with the final phase, production and deployment, is a formality, with a fixed-price contract being negotiated with the sole source.

Acquisition strategies for SD SPOs are fairly limited in number, given the nature of the product and the spacecraft industry and budgetary constraints. There has never been a case of prototype fly-off or dual-sourcing of the spacecraft itself. Component break-out has been tried infrequently, such as in the DSCS III program, where the travelling wave tube amplifiers were procured from two sources to insure an adequate supply of these high-risk components (27:78-85). Only since

the Congress opened up the options for multi-year procurement in the 1982 DOD Authorization Act have SPOs had much leeway in choosing their contracting approach (18:1-3; 111:169).

The types of contracts used in this process reflect the degree of risk involved. The initial system design concept studies are low-risk, paperwork exercises, and are purchased through fixed-price type contracts. Here the burden of cost control is entirely on the contractor, although there is evidence that firms spend much more than the price of the contract on their preparation effort (68:74). Their motivation is based in the nature of the opportunities to compete for a system. It is almost unheard of that a firm not involved in preparing a concept study is a serious contender for the concept validation or full-scale development contracts. Instead, the three to five firms winning the study contracts go on to compete for the concept validation contracts. The full-scale development and production contracts will inevitably be awarded to one of winners of the second phase contracts. So a firm's main opportunities to compete for a major system are in the first two phases of the program.

The risk increases significantly in the full-scale development phase, when the contractor attempts to translate the paperwork into actual hardware (68:75). All of the major space systems now in production--DMSP, DSCS III, DSP, and GPS--incurred the majority of their cost and schedule overruns in this phase (55). As of September, 1985, for example, there had been 284 contract modification orders written to the DSCS III

full-scale development contract (1). The more the requirement stretches the limits of technology, the more likely the contractor will run into problems. The greater risk associated with the development stage is reflected in the cost-plus-type contracts used, under which the contractor is reimbursed for all "reasonable, allowable, and allocable costs incurred," plus a fixed amount of profit--an award or incentive fee (38:15-2).

In fact, the Milstar program, considered the most technically complex and ambitious military satellite program ever undertaken, "raised serious questions about the industry's ability to deliver within cost and on schedule" (119). The very advanced technology requirements of the Milstar program was cited as the prime reason for teaming by bidders on the development contract (63). Each of the three bidders in the concept validation phase--Boeing, TRW, and Lockheed--was allied with other major space firms--Ball, Ford Aerospace, Hughes, and RCA among them--in their proposal. Teaming works to reduce the perception of risk on both sides of the contract. The composition and size of the teams "eroded [DOD] concern about one company's having enough capability or experience to build the system" (119). And by working out cooperative agreements at the outset, the team members can spread out the risk of cancellation, which, in the case of Milstar--a costly, complex, and controversial program, was considered high.

The production contract is typically some form of fixed-price contract, since the majority of development risks and

design changes are assumed to have occurred in the full-scale development phase. A number of observers have criticized this assumption, pointing out that design changes often occur after the contract award, and each has to be negotiated and priced with the contractor (3; 72; 73; 136:171). A comparison of Air Force and commercial comsat development and procurement contracts found that the Air Force made a greater number of changes to their contracts, but that this was largely because each contract change is treated separately, while commercial programs tend to incorporate a number of changes into a single contract modification (127:10). The same study compared two similar comsat acquisitions--DSCS II and INTELSAT-IV--and found that while the price change on the DSCS II program was 19%, versus 2% on the INTELSAT-IV program, the final overall cost of the DOD system was slightly less than the commercial (127:43). The authors conclude that the difference in price changes was in part due to the Air Force's having underestimated the original cost (127:43).

A recent development in the acquisition strategies for the production phase of spacecraft is the use of multi-year procurement (MYP) contracts. Out of the six major AF MYP contracts, three are for the production of space systems--DMSP Block 5-D, DSCS III, and GPS satellites. The DOD has argued that MYP contracts offer substantial savings in the production phase, when requirements and designs have stabilized. Under Public Law 97-86, the criteria used to determine when MYP contracts are appropriate are (111:172-3):

Table XII.

Estimated MYP Savings for Space Systems.

System	Annual Buy Cost	MYP Cost	Savings
DMSF-5D	\$ 295 M	\$ 246 M	\$ 49 M
DSCS-III	916	834	82
GPS	1620	1343	212

Sources: 111:176; 73:20.

1. Benefit to the government from cost avoidance savings or improved delivery schedule.
2. Stable requirement--firm production rate, fiscal year phasing, and quantities; low risk of cancellation.
3. Stable funding.
4. Stable configuration--relatively few changes in design; the cost of changes should not drive costs beyond the funding profile or significantly affect MYP savings.
5. Cost confidence such that a fixed-price type contract is appropriate.

The estimated savings from using MYP contracts rather than annual procurements for the three space systems are listed in Table XII. The GAO has disputed Air Force estimates of MYP savings, citing the failure to consider the social discount rate and the impact of changes to launch schedules (73). In addition, contractors have expressed a number of concerns about MYP contracts (111:174-175):

1. Cancellation protection--overhead and opportunity costs are not adequately covered by cancellation ceilings.
2. Excessive risk--long-term contracts do not allow for adjustments due to factors beyond the contractors' control, such as supply conditions and launch vehicle changes.
3. Reduced profitability--no coverage of imputed interest charges on working capital.
4. Changing economic conditions--risk of unpredicted inflation in labor rates, compensation, materials, overhead.

Indeed, unless the MYP contract addresses the borrowing capability of the firm, its excess capacity, capital assets, cash flow, and labor market, it may not significantly improve the extent of contractor capital investment (113:18-9). Despite these issues, however, the current DOD policy is to encourage the increased use of MYP contracts in the production phase (52).

In all but sealed-bid and sole-source procurements, the award of a major contract is determined through a source selection. The sellers have little or no direct influence on the choice. The source selection process is conducted in tight confidentiality, to avoid any possible coercion from bidders. The proposals, stripped of any company identifiers, are evaluated by knowledgeable personnel selected from technical and management areas relating to the system, assigned full-time to the source selection. The evaluation teams submit the scores of the respective proposals to the source selection board, which weighs these with other criteria, such as proposed cost, past performance, schedule realism, contractor capability, and cost credibility (115:34; 108:361-85). The recommendation of the board is presented to the commander of Space Division for the final decision. Once the contractor has been selected, negotiators begin working out the terms of the contract, including the actual price and fee structure. Finally, when funds have been authorized, the contract is signed.

Along with the phasing and contractual structure of the space system acquisition process, the extended development and deployment periods and instabilities in requirements, management, and specifications influence the risks in a program, and thus, the competitive behavior of spacecraft manufacturers (5:1 June 1983). As described in the preceding chapter, the process of building a spacecraft is itself lengthy, taking from one to three years. The concept validation and full-scale development phases can last as long as nine years (55). The concept validation and preliminary design phases of the DSCS III program, for example, lasted two years, and the full-scale development phase lasted almost five (55). The more controversial and complicated the requirement, the longer the process takes. The first phase of the GPS program lasted over four years, and the production contract was signed nearly nine years after the program began (55). The length of time of a program indirectly contributes to instabilities in management. Due to the Air Force practice of transferring its personnel every three or four years, program managers change several times over its lifetime, and the overall level of knowledge of the system in the SPD remains low.

A variety of factors influence a program's schedule. The biggest factor is the complexity of the technologies involved (5:7 December 1984). The explosion of new developments in the field of electronics have allowed for significant leaps in sensing, computing, control, and signal processing systems, but

along with these advances have come almost geometric increases in the resources needed to verify and validate the capabilities of these systems (5:20 April 1984). In the first three years of the GPS program, problems with the navigation signal transmitter and receiver systems caused a nine-month delay in the development schedule (75:16-19). Only 2 of the 10 atomic clocks (a critical element of the navigation payload) on the GPS prototype satellites had no problems, and 5 of the other 8 failed completely (74:9-11). Problems stemming from the more sophisticated capabilities of the DSCS III design added nearly five months to the testing schedule (126).

These delays can affect the launch schedule as well, resulting in further delays. A SPO has to sign up for a launch vehicle two to three years in advance. A satellite's orbit and the availability of boosters and launch facilities create "launch windows"--periods during which a launch is feasible. Depending on the program, these windows can be months or even years apart. The 5-month testing delay in the DSCS III program combined with other factors to result in an 18-month delay in the first launch date (126).

The oversight structure described earlier contributes to the perception of program instability. Changes in DOD and federal budgets introduce the possibility of a program's funding being reduced, stretched out, or even cut. The memory of the cancellation of the Manned Orbital Laboratory program in 1969 and subsequent transfers and layoffs are still fresh in

the minds of senior Air Force and industry space managers (130:198). The GPS program was the subject of 9 critical General Accounting Office reports between 1977 and 1983, and the multi-year procurement of DSCS III spacecraft was rejected by the Congress the first year it was proposed (73:19; 5:3 Jun 83).

The process by which Space Division acquires space systems, is characterized, then, by the program and contractual structure, and the inherent risks of advanced space technology, compounded by lengthy program timelines and schedule and funding changes due to factors often beyond the control of the contractor. The opportunity to compete truly exists only at the outset of a program. The rewards, however, can be high-dollar, multi-year contracts.

Sellers' Responses. The nature of the defense space system acquisition process explains much of why many aerospace firms are eagerly vying for Strategic Defense Initiative (SDI) R & D contracts: "If you don't get one, you'll be behind the power curve" (25). A firm can't afford to bid on every program that comes along, though. The cost of preparing a proposal tends to be proportional to the size of the program involved, and this cost is reportedly increasing (55).

The response of sellers to Requests for Proposals for space systems is influenced by a variety of factors: the firm's design and production capabilities, existing and projected demands, its perceptions about its competition, its confidence about the program and the prospect of production

contracts, and its long-range competitive strategy (108:405-6). These factors also have much to do with the strategic group a firm finds itself in. This section will attempt to show how competition for Space Division contracts reflects the character of the strategic groups in the spacecraft industry.

The three strategic groups described in the previous chapter are: the "Big Three" firms heavily involved in the commercial market--Ford Aerospace, Hughes, and RCA; the largest group, comprised of firms like General Electric, Lockheed, and Rockwell, which possess substantial space development and production resources and who are overwhelmingly reliant on NASA and the DOD for their space sales; and Fairchild and Ball, which lack the financial clout of the other industry members, and which have met with the most success in building scientific satellites for the DOD and NASA. These groups are not necessarily static or distinct from each other. Firms from different groups often compete for the same contracts. Their motivations, however, differ in much the same way that their intra-industry positions differ.

For the group with the smallest market shares, Ball and Fairchild, the choice of contracts is influenced both by the need to maintain their specialty and the desire to break into other markets. Ball proposed a low-cost satellite missile warning system to the Air Force in 1982 in an attempt to expand into operational systems (124:69). It secured its largest contract ever for the Infrared Astronomy Satellite (IRAS) to

develop its expertise with larger spacecraft, but incurred \$20 million in cost overruns because it underestimated the problems associated with a cryogenically-cooled system (124:73). Ball is also exploring the commercial market with its design for a small Earth resources satellite (Aeros). Fairchild has had only one success in the DOD market, providing the upper stages for the first series of GPS satellites. Instead, it has concentrated on contracts with NASA on scientific programs or systems with high applications potential. It has been working since the late 1970s on a multi-mission spacecraft design for NASA (59: 92). A version of this design, the Leasecraft satellite, will carry scientific and commercial payloads which can be periodically serviced by the Space Shuttle. Fairchild has also attempted to interest DOD and foreign customers in the multi-mission design as an alternative to building separate satellites.

Firms with a long history of major DOD and NASA contracts tend to obey the "follow-on imperative"--that is, they seek to maintain or expand their existing levels of employment and production capacity (88:304; 85:27-30). The larger the size of their facilities and workforce dedicated to government space contracts, the more pressure there is on a firm to keep a steady stream of contracts coming. To this end, firms like Lockheed and TRW "have planning groups, whose sole function is to choose suitable successors for the weapons that are currently being produced and who work closely with similar groups in the services" (85:30). Rockwell, for example, is

currently working on the multi-year contract for GPS satellites, producing an average of eight a year. If it wins the contract for replenishment satellites, its production line will remain open through the early 1990s, but at a rate of four satellites a year. Consequently, it is working on design concept studies for a NASA system--TOPEX--and two SDI projects (5:26 Mar 84; 133).

The competition for SDI contracts reflects the follow-on imperative felt by the firms in the middle group. Four SDI programs are considered to have a good chance of producing major spacecraft contracts (133). Boeing, Lockheed, Martin Marietta, and Rockwell have won design concept study contracts for the Space-Based Laser System. Boeing, Lockheed, and TRW are preparing studies on the Satellite Defense System. Lockheed, Rockwell, and TRW are working on the Space Surveillance and Tracking project, and General Electric, Grumman, Lockheed, and TRW have study contracts for the Boost Surveillance and Tracking project. The study contracts are not substantial--the prices range from \$1 million to \$6 million (1). But, as stated earlier, these companies believe that the early bird gets the worm. The follow-on imperative equates to maintaining or expanding market shares. This is clearly demonstrated by the fact that Lockheed, which currently has the largest share of the defense spacecraft market, is involved in all four projects. Boeing and TRW are in close competition with Lockheed in terms of total contract dollars (40). These

firms were also in competition in the concept validation phase of the Milstar program (26). The Milstar program is expected to be the last major defense space program to begin production before the end of the decade (119:51). The competition for the full-scale development contract, between Lockheed and TRW, both of whom had facilities involved in major production contracts (Space Telescope and DSF, respectively) which would run out about the time that the real work on Milstar would begin, was reported to be very fierce (119:51). "There was cheering in the halls when Lockheed won Milstar" (33).

Of the "Big Three", only Hughes has shown much interest in the SDI program (40). This lack of interest in the long-term opportunities of the SDI program reflects a number of characteristics of this strategic group. First, all three companies are looking to develop their shares of the commercial market, coming out with new designs aimed at attracting Third World customers and others eager to enter the direct broadcasting (DBS) business, and trying to stay ahead of competition from Japan, Britain, and France (30; 71). Second, with their growing commercial sales, these firms are less dependent on prime defense contracts to keep their personnel and facilities busy (63). Finally, these firms are not withdrawing from the DOD or NASA markets completely, but they can afford to be more selective in their bids. They compete for systems they have specialized in. RCA is involved in the follow-on to its DMSP satellites, and Hughes has won a contract for the successor to the Defense Support Program (DSP).

spacecraft (55). They are also working as subcontractors to firms in the middle group--Hughes and RCA are both members of Lockheed's Milstar team, and Ford Aerospace was teamed with Boeing on its bid in the concept validation phase of Milstar (119).

Performance

Definition and Measures. A market's performance is measured by its end results--the outputs, prices, costs, designs, and rate of technological advancement of its firms (19:10). Stekler and others have argued that traditional measures of performance--the external and internal efficiencies of plants and firms, profit rates, and the ratio of selling costs to sales revenue--"are not totally applicable to the aerospace industry" (136:154; 108:56-7). External efficiencies, for example, are affected by government procurement awards aimed merely at keeping production lines from going out of existence (136:154; 88:308). Low profit rates are often taken to be an indicator of an efficient industry; in the case of defense-oriented firms, their low profits may have no relation to their efficiency (68:86-7). The goal of firms with a large percentage of defense sales may not be to maximize profits, but to maximize the extent of government subsidization of research, development, and production facilities (99:314-5; 95:30). This is because they perceive unacceptably high costs associated with converting their operations to a commercial market (68:48-50).

In order to determine how to measure the performance of the defense spacecraft market, it is useful to consider the main reason for the the market's existence--the development and acquisition of spacecraft to support national security needs. As mentioned earlier, the primary criteria by which the DOD compares alternative systems are state of the art advancement, operational performance, total life-cycle cost, time, and uncertainty. How well the market has performed is a matter of how well it has proceeded towards optimal results in terms of these criteria. Optimization of technology, performance, cost, time and uncertainty can be viewed as the public's goals for the market.

These defense acquisition goals can be placed into the context of traditional market performance goals. Shepherd identifies these goals as (121:32):

1. Efficiency, which includes:
 - a. Dynamic efficiency
 - b. Internal efficiency
 - c. Allocative efficiency
2. Equity in the distribution of wealth and income.

Technological state of the art advancement equates with dynamic efficiency--the rate of innovation and invention. Unfortunately, as Bain has written, "meaningful appraisal or performance in the dimension of innovational progress is not possible": "We lack an empirically applicable standard for adequate progressiveness" (19:421,501). Sosnick says that if there are no personnel or resources dedicated to research into product or process improvements, it indicates undesirable

market performance, but acknowledges that beyond that it is not possible to distinguish good performance from bad in this dimension (127:846). Scherer uses several approaches to compare the progress of innovation in different industries, but stipulates that his analysis does not apply to R & D work carried out under government contracts (117:409). The R & D contractor accepts little of the risk and acts under the detailed direction of the government. Since over 75% of R & D funds in the aerospace industry are provided by the government, it is difficult to assess the rate of technological progress resulting from private investment. For this reason, this study does not attempt to evaluate the performance of the spacecraft market in this dimension.

Minimizing costs and system acquisition times are goals related to internal efficiency. As has been described, the characteristics of the management of DOD programs have much to do with their cost and schedule performance. This does not mean, however, that trends in firm-related efficiencies cannot be separated from trends in DOD program management. Productivity measures such as value-added per manhour, as well as qualitative production process innovations can give some indication of internal efficiencies. In addition, although it may not be possible always to separate DOD from industry influences on program costs and schedules, it is worthwhile to examine their trends as an indicator of the efficiency of the market--the combined actions of the buyer and the sellers. Finally, reducing both the uncertainty of program and the total

cost relates to allocative efficiency, since this often comes down to a matter of risk-bearing and profit-taking.

Determining the proper allocation of risks and costs between the DOD and the prime contractor and agreeing on the profit margin appropriate to the investment and risk assumed by the prime contractor are major goals of a program manager.

Optimizing program uncertainty equates to optimizing the distribution of risk between the DOD and the contractor. Peck and Scherer have described how contractor risk-bearing can be viewed as an aspect of both internal and allocative efficiency (108:528). The purpose of risk-bearing is "to minimize under conditions of uncertainty the expected cost (actual cost weighted by relevant probability values) of accomplishing a result." Risk-bearing is also a matter of allocative efficiency, since it "involves the optimization of resource commitments among alternative payoff possibilities." Defense contractors have often used risk as the justification for the profits they earn on relatively small capital investments (16:98). Some measure of how well the market has performed in terms of allocative efficiency can be obtained by evaluating profit rates in light of the risks borne by contractors.

The nature of profits or losses in the industry is also an aspect of equity. Scherer has written (118:3-4):

Equity is a notoriously slippery concept, but it implies at least that producers do not secure rewards far in excess of what is needed to call forth the amount of services supplied.

Profit is the most tangible reward secured by a defense

contractor for his services (108:214). Producers earning monopolistic excess profits while turning out systems with major cost and schedule overruns is an indication of clearly undesirable performance with respect to equity. Bain also views profit performance as an aspect of both allocative efficiency and equity, but adds that it is not sufficient in itself to cover the issue of income distribution, since it says little about distribution of personnel income. For this reason, the discussion of equity in the spacecraft market will limit itself to the question of the rewards--profits--earned by contractors.

Thus, although traditional measures of performance may not entirely apply to a defense-oriented market, there are ways to describe how this market performs in relation to the goals of internal and allocative efficiency and equity. How this performance may be judged, given the structure and conduct of the market and their interaction, is discussed in the next chapter.

Internal Efficiency. Firms aim for internal efficiency by minimizing their production costs. While it is not feasible to determine the cost curves for spacecraft manufacturers, it is possible to infer something about the internal efficiency of the market from facts about productivity in the industry and the cost and schedule performance of defense satellite programs.

A primary measure of productivity is the value added by

Table XIII.

Real Value Added per Production Worker per Hour, 1963-1982.

SIC	Industry	1963	1967	1972	1977	1982
3761	Missiles, Space	10.38	28.98	32.23	36.01	40.94
3573	Computers	(NA)	22.87	26.78	32.61	31.94
3721	Aircraft	13.70	13.42	19.62	23.11	22.49
3795	Tanks	11.89	8.65	12.41	16.31	22.19
3662	Comm. Equipment	13.39	14.26	18.08	21.85	21.42
3724	Aircraft Engines	(NA)	(NA)	15.93	16.87	17.21
3483	Ammunition	(NA)	8.77	9.83	14.09	17.17
3728	Aircraft Parts	(NA)	(NA)	14.69	16.57	16.85
3731	Shipbuilding	6.76	7.66	8.06	11.29	10.93
All Manufacturing		10.08	11.79	13.26	15.13	13.84

Sources: 44; 45; 46; 47; 49:746; 8:26-27; and calculations by the author.

Note: Figures adjusted for inflation, using the Federal Price Deflators for SICs 3721, 3724, 3728, and 3761, and the Federal Price Deflators for Durable Goods Defense Purchases for all other SICs (1972 = 100).

manufacture, defined as the value of shipments less the cost of materials, per worker per hour. As can be seen from Table XIV, the missiles and space industry has, since 1967, led other defense industries in this category. But simple value-added figures do not provide a fair basis for evaluating an industry's productivity.

A more revealing statistic is the increase of value-added per worker over the last 15 years. An efficient industry should exhibit a steady increase in worker productivity. The figures for value-added per production worker hour have only been reported for the years 1967 and 1982 for SIC 37612, Complete Space Vehicles, due to problems of disclosure (47: 44; 45: 46). The figures for 1967 and 1982 are \$29.50 and \$70.73.

Table XIV.

Increase in Real Value-Added per Production
Worker Hour, 1967-1982.

SIC	Industry	% Increase, 1967-1982
3795	Tanks	157 %
3483	Ammunition	96
3721	Aircraft	68
3662	Radio & TV Comm. Equipment	50
3731	Shipbuilding	43
3761	Missiles and Space	41
3573	Electronic Computing Equipment	40
	All Manufacturing	17
37612	Complete Space Vehicles	- 29

Source: Derived from Table 2.

respectively. Adjusted by the Federal Price Deflators for SIC 3761, these figures are \$41.14 and \$29.06, representing a 29% decrease over the 15-year period.

This is the worst record of productivity progress exhibited in any defense industry. The equivalent figures for SIC 37611, Complete Missiles, adjusted for inflation, are \$16.64 and \$36.81, which represent a 121% increase. The rate of increase for the other 4-digit SIC defense industries for which 1967 and 1982 figures are available are listed in Table XIV. (The aggregate value-added figure for SIC 3761 is higher than the respective figures for 37611 and 37612 due to the contribution of the remaining product classes, which had an aggregate value-added figure of \$51.70.) The SIC 3761 industry ranks near the bottom of this group; considering that, of the

Table XV.

Average Hourly Earnings of Production Workers, 1963-1982.

SIC	Industry	1963	1967	1972	1977	1982
3761	Missiles, Space	4.89	5.15	6.29	6.22	5.63
3573	Computers	(NA)	3.78	4.19	3.92	3.73
3721	Aircraft	4.38	4.62	5.14	5.24	5.60
3795	Tanks	4.07	4.12	5.21	5.45	5.44
3724	Aircraft Engines	(NA)	(NA)	4.83	5.20	5.12
3662	Comm. Equipment	4.00	4.25	4.51	4.33	4.18
3728	Aircraft Parts	(NA)	(NA)	4.86	5.03	4.88
3483	Ammunition	(NA)	3.77	3.79	3.91	3.95
3731	Shipbuilding	4.30	4.45	4.51	4.50	4.63
	All Manufacturing	3.46	3.66	3.95	4.06	3.79

Sources: 44; 45; 46; 47; 49:746; and calculations by the author.
 Note: Figures adjusted for inflation using Consumer Price Index (1972 = 100).

two major segments of this industry, only guided missiles showed a positive increase in value-added, these figures clearly indicate that the productivity trend in the spacecraft industry is significantly worse than in other defense industries.

In contrast, worker compensation in the spacecraft industry remained the highest of all defense industries (see Table XV). Average hourly earnings of production workers in SIC 37612, Complete Space Vehicles, adjusted for inflation, increased 8.8% from \$5.44 an hour in 1967 to \$5.92 in 1982. This compares to a 2.3% increase over the same period for SIC 37611, Complete Missiles, and a 3.5% increase for all manufacturing industries. Moreover, wages in SIC 37612 are the highest in the missiles and space industry, which in

Table XVI.

Average Annual Pay for All Employees, 1966-1982.

SIC	Industry	1967	1972	1977	1982
3761	Missiles, Space	\$13,059	\$14,795	\$14,795	\$13,749
3573	Computers	10,180	11,521	10,760	10,359
3721	Aircraft	10,180	12,369	12,320	12,198
3795	Tanks	9,626	11,017	11,605	11,385
3724	Aircraft Engines	(NA)	12,002	12,615	11,759
3662	Comm. Equipment	10,911	11,244	10,687	10,234
3728	Aircraft Parts	(NA)	11,332	11,538	11,198
3483	Ammunition	(NA)	8,727	9,059	8,838
3731	Shipbuilding	9,714	9,836	9,757	9,715
All Manufacturing		8,521	9,210	9,317	8,626

Sources: 44; 45; 46; 47; 49:746; and calculations by the author.

Note: Figures adjusted for inflation using Consumer Price Index (1972 = 100).

turn consistently have been highest of all defense industries. The average annual pay for all workers in the missiles and space industry has also been consistently led defense industries since the 1960s (see Table XVI). A recent survey of compensation by 12 aerospace companies at specific facilities, including a major spacecraft plant (TRW Redondo Beach, CA), found that factory and clerical pay averaged 8% over the Bureau of Labor Statistics (BLS) mean for similar positions (71:6,9). The survey also reported that the average employee received 34% more in total compensation and benefits than the average manufacturing employee (71:10-11).

A major contribution to the decrease in measured productivity may be the increasing cost of materials in relation to the value of shipments. The ratio of the cost of

materials to the value of shipments for SIC 37612 almost doubled between 1967 and 1982, from .304 in 1967 to .573 in 1982. For the same period, this ratio increased by only 17% in SIC 37611. In four-digit industries, costs of materials in proportion to shipments increased by 21% for missiles and space (SIC 3761) and 10% for aircraft (SIC 3721). The ratio for all manufacturing industries increased 7% during this period (49:746).

The dramatic increase in the cost of materials relative to the value of shipments may be due to a combination of factors. As described in the previous chapter, the majority of materials costs in the spacecraft industry are for finished products, particularly electronic equipment. To be space-qualified, these subsystems and components must be manufactured under tight quality controls and subjected to rigorous tests. These measures would be expected to increase the cost of a space-qualified part over that of one for terrestrial use. Moreover, the understanding of the space environment and the design life and unit cost of spacecraft have all increased since the 1960s. So the specifications for components are more exacting now, and there is greater emphasis on reliability (17:15). Components must be able to operate years longer than the parts on 1960s spacecraft. The cost of the failure of a component can now result in the loss of hundreds of millions of dollars, compared to tens of millions in the 1960s.

Compounding increase in the need for quality control and

reliability is the growth of alternative markets for some components (3). Solar power cells, for example, are an essential element of all spacecraft electrical generation systems. The market for solar cells was rather limited in the 1960s, and the space business represented a major buyer (44). With the rise of interest in alternative energy sources, however, the commercial market for solar cells has grown dramatically, and is far more profitable than the space market (3; 47). Given this situation, the small quantity of most spacecraft parts orders, and their extensive quality control and reliability specifications, the spacecraft manufacturer has little leverage in controlling the price of these materials. And the problem is exacerbated by when the buyer faces a sole source of supply (3).

Clearly, the spacecraft industry has had little success in offsetting increases in the costs of inputs with increases in productivity. This is largely because the spacecraft industry is still a relatively immature industry, whose product is "built the old-fashioned way--by hand" (33). The industry has not ignored new production techniques, but since spacecraft are custom-built and incorporate small quantities of a large number of different parts, these innovations must be flexible and cost-effective for small production runs (55:35). For this reason, said one Rockwell official, "An investment on the scale of robotics is out of the question" (57). Many of the critical manufacturing and assembly tasks

are still manual (33). As discussed in the previous chapter, a major cost in spacecraft production is not manufacture itself, but qualification testing, and this is where some savings have occurred (5:15 Jan 85; 56). The use of computer-aided design (CAD) has allowed stresses, loads, and resonant frequencies to be more precisely calculated, thereby reducing the amount of shock and vibration testing required (17:21). Rockwell estimates its use of automated test equipment reduced the time needed to test the GPS satellites from 43 weeks to 34 (57).

Internal efficiencies related to economies of scale have only recently been observed in the industry, in part due to multi-year procurements. The best documented example of this is Rockwell's experience with the GPS program. The guaranteed order for 28 satellites enabled Rockwell to make one-time buys from suppliers, allowing the subcontractors to gear up for economical runs, rather than having to start up and shut down on a year-by-year basis (3; 123). The size and period of the contract (\$1.2 billion over five years) provided the stability for Rockwell to invest over \$40 million in new production and test facilities. Rockwell hired an industrial architecture and engineering firm to study the production process and design a production line organized into stations. At these stations, equipment is dedicated to their respective tasks, cutting down on time previously needed to move, set-up, and check out equipment when satellites were assembled one at a time (57).

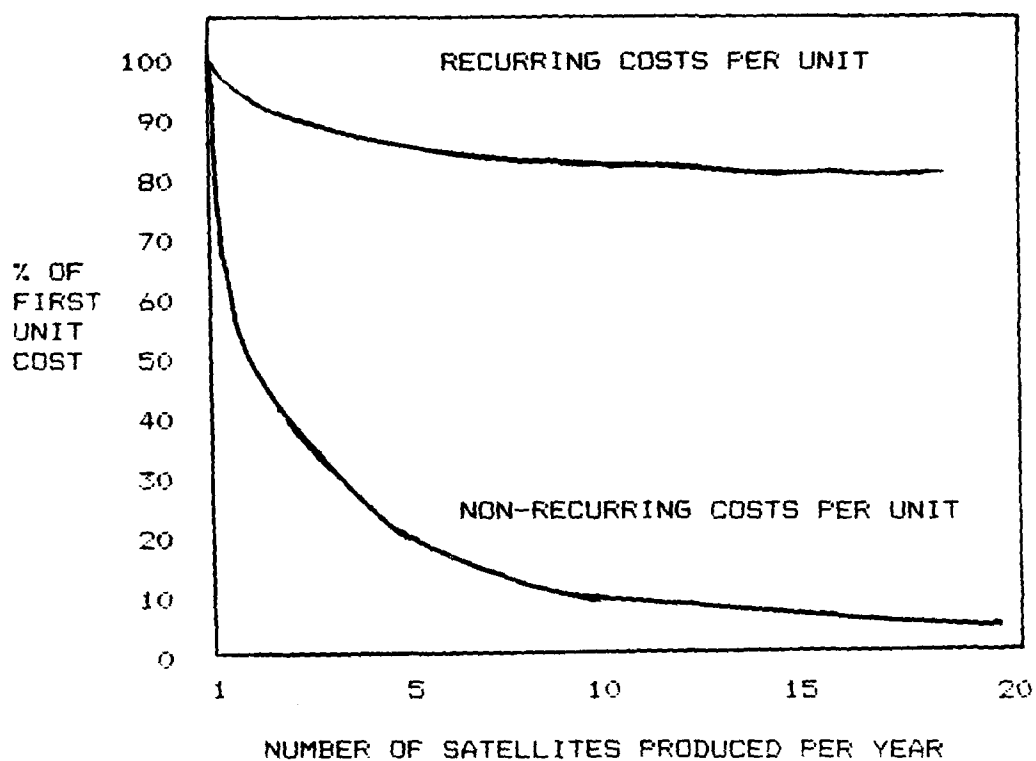
The relatively high rate of production (8 a year) realizes savings from the learning curves of production and test personnel, as well as from the full employment of these crews (see Figure 5). In the past, there were large idle periods between satellites, and the company would have to choose between paying the crews during idle times or laying them off. The latter solution was often the more expensive, particularly in the case of test technicians, who were in high demand among the aerospace firms in the Los Angeles area (56).

As explained earlier, it is difficult to isolate which cost changes are due to contractor performance, which to the program management, and which to other factors such as the availability of launch vehicles. A study recently completed by Air Force Systems Command did attempt such an analysis for a number of programs, including some space programs, but this author was unable to obtain this data. For this reason, this study looks at cost overruns as indicators of the efficiency of the market, and does not assign particular responsibility to the industry or the DOD.

Peck and Scherer define efficiency in major systems acquisitions as (108:509):

[A]ccomplishing a desired result with the minimum possible expenditure of resources. A result, in this sense, is obtaining a weapon system of a certain quality in a certain time.

One statistic they use in evaluating program performance is the development cost factor, which is the ratio of actual program cost to the original cost estimate (108:429). This measure



- Notes:
1. Curves derived from Space Division Standard Spacecraft Cost Model.
 2. Recurring costs include costs of materials, facilities, labor, and testing.
 3. Non-recurring costs include costs of design and prototype development.
 4. The ratio of recurring to non-recurring costs varies widely among programs.

Figure 5. Effect of Annual Production Rate on Unit Costs of Satellites (3).

Table XVII.
Space Program Cost Factors.

Program	Base Year	Original Estimate	Projected Total Cost	Cost Factor
DMSP	1975	\$ 842.5 M	\$ 2262.5 M	2.69
DSCS III	1977	1053.7	2032.6	1.93
DSP	1978	4731.6	6268.3	1.33
GFS	1979	1730.8	2521.7	1.46

Note: Projected costs as of 31 July 85 Systems Acquisition Report.

Source: 5: 20 Aug 85.

bears close resemblance to the degree of X-inefficiency, which is defined as the ratio of excess costs to minimum costs (121:32).

Cost factors are easily obtained from the Systems Acquisition Reports published quarterly by the Department of Defense at the request of the Congress. These list the current and cumulative actual and projected cost escalations for selected weapons systems. The most recent figures for four space programs, along with their development cost factors, are listed in Table XVII. Every program has run over its original cost estimate, but their performance should be considered in relation to other programs. The average cost factors for Army, Navy, and Air Force programs in the same report were 2.22, 1.78, and 1.88, respectively, and the average for all DOD programs was 1.87. With the exception of the DMSP program, which had two on-orbit failures in 1976 whose replacement accounts for much of the cost increase, the

programs were within the overall averages for the services. This compares favorably to the performance of 12 major systems programs in the late 1950s-early 1960s period studied by Peck and Scherer, which had an average cost factor of 3.2 (108:429). The decrease in cost overruns is attributable to improved cost estimation, the shift from cost-plus to fixed-price contracts since the early 1960s, and the implementation of various cost-control statutes and regulations (4:A26).

Gansler holds that "The most obvious result of the failure of the market in the case of defense is the high and rising price of defense equipment. . . By contrast, commercial equipment has been going down in constant-dollar price, while its performance has been going up" (68:83). These observations are not entirely valid in the space market. First, while it is true that total space system costs are increasing, it is rather meaningless simply to compare bottom-line price tags between systems designed and produced ten or twenty years apart, since the systems are equivalent in name only (5:20 Apr 84). The capabilities of both civilian and military satellites have increased steadily over the last 25 years. Figures 6 through 9 show how design life, power, weight, and capacity has increased for both military and civilian communications satellites. Table XVIII shows how capabilities and costs have increased over three generations of defense communications satellites. In addition to the capability figures listed in Table XVIII, the three systems differ in number, power, coverage, and

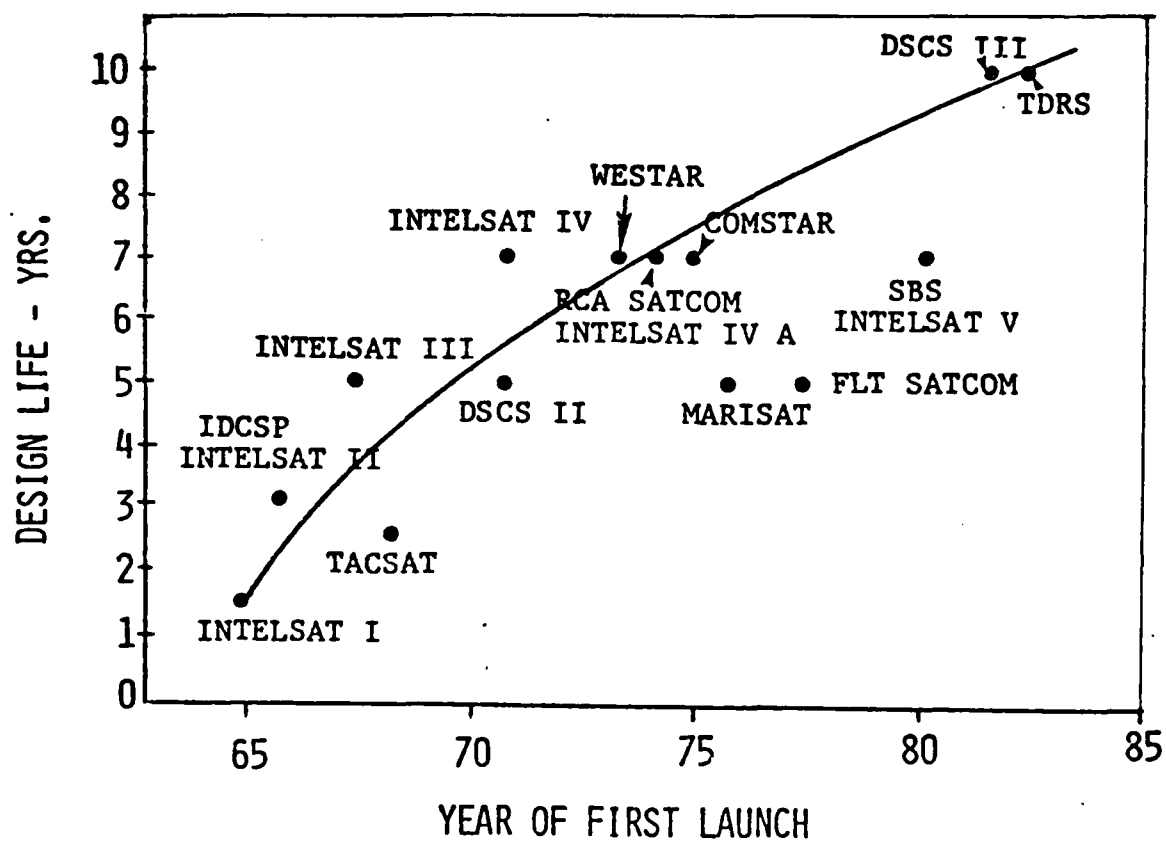


Figure 6. Trend in Communications Satellite Design Lives (3).

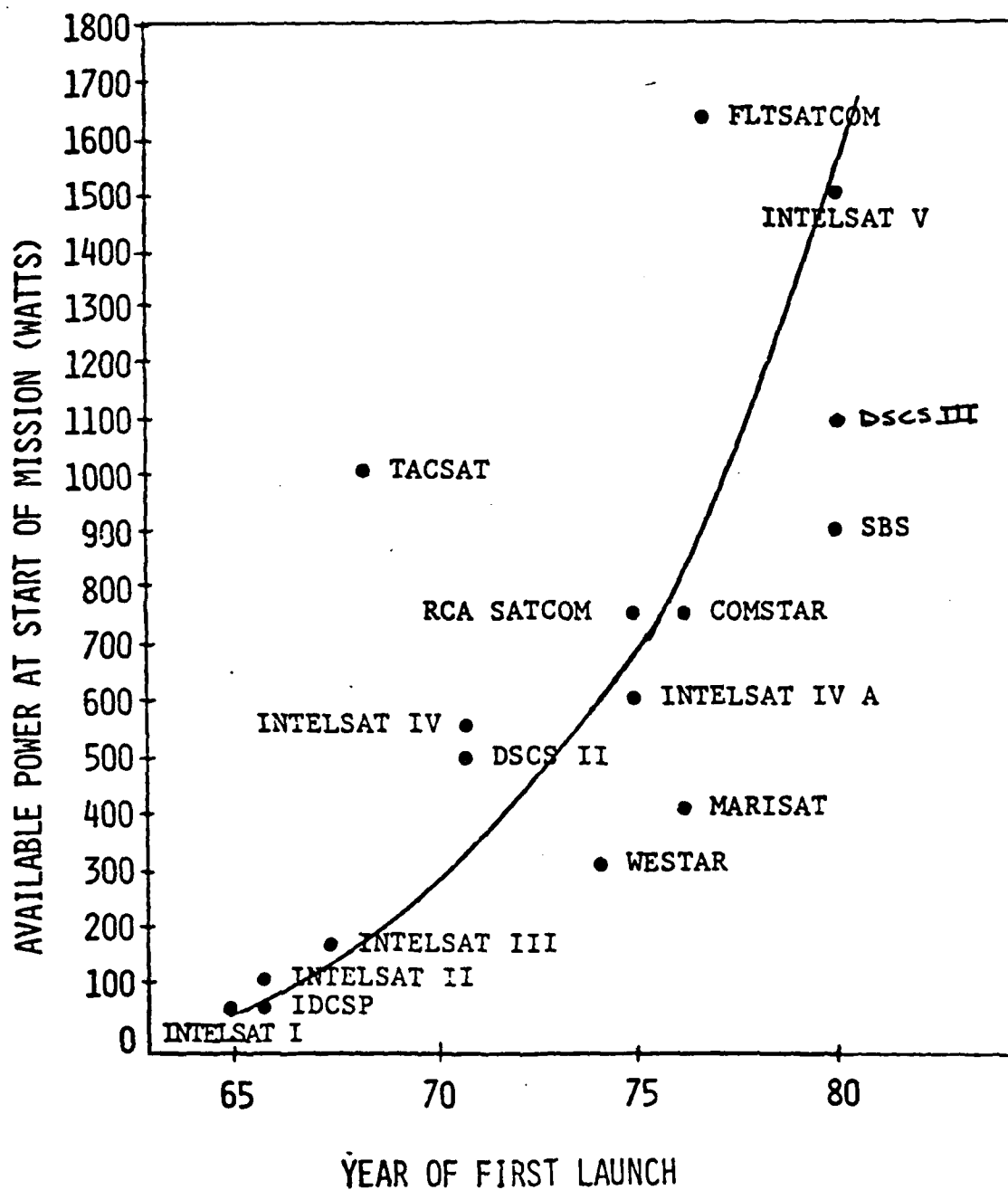


Figure 7. Trend in Communications Satellite Start of Mission Power (3).

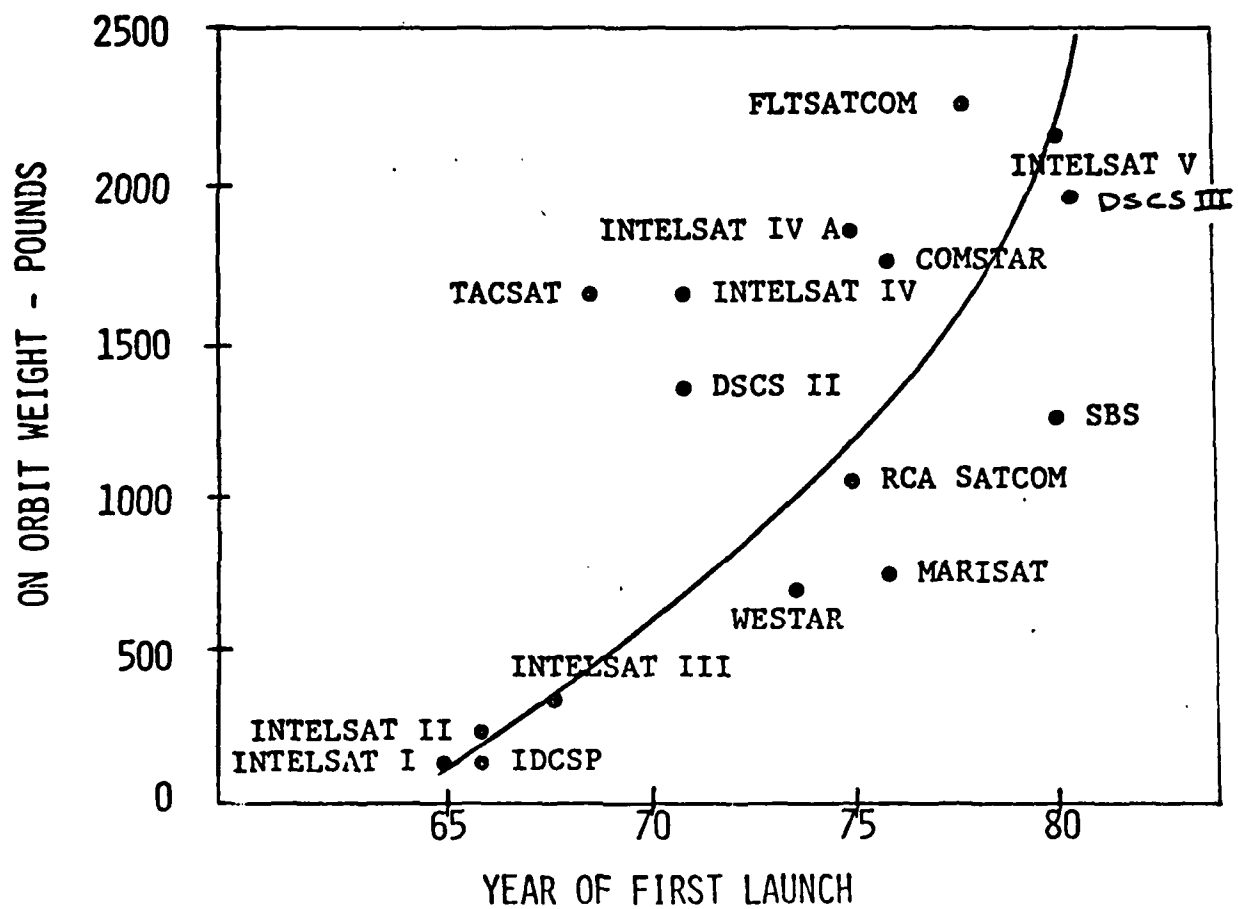


Figure 8. Trend in Communications Satellite On-Orbit Weight (3).

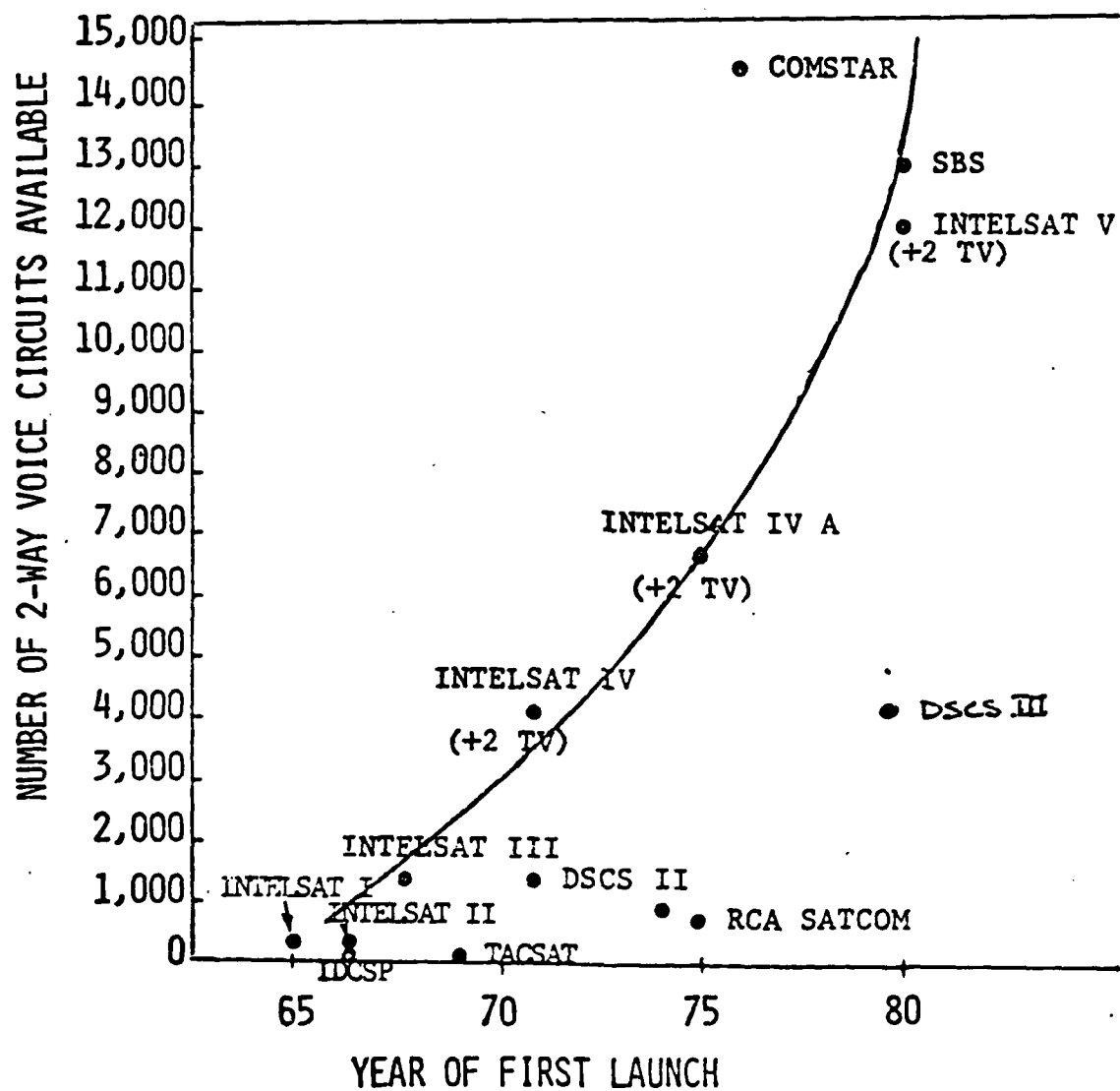


Figure 9. Trend in Communications Satellite Traffic Capacity (3).

Table XVIII.

Capabilities of Defense Communications Satellites.

System	First Launched	Weight (Dry)	Power (Watts)	Channels Available	Design Life	Unit Cost
IDCSP	1966	45.3 kg	40	1	3 yrs	\$ 3 M
DSCS II	1971	536.0 kg	535	4	5 yrs	\$ 60 M
DSCS III	1982	853.0 kg	1150	6	10 yrs	\$136 M

Note: Unit costs in constant 1983 dollars.

Sources: 127:79; 131.

steerability of antennas, anti-jam features, survivability, and variety of missions they can support--consistently improving with each generation (129). Simply comparing the increase in unit costs over this period ignores these improvements in the capabilities of the systems. A fair comparison would require an in-depth breakdown of capabilities and costs, combined with determination of appropriate weighting factors for technological differences.

Second, it is unfair to directly compare the unit costs of military and commercial space systems, because their designs differ significantly. Military satellites must be able to carry out their missions in the face of the threat of attack, while commercial satellites are designed to operate in a peacetime environment only. For this reason, the design of a military communications satellite, for example, "trades off a large portion of its potential communications capacity in return for nuclear hardening and antijam capabilities not found

on commercial systems" (127:8). Thus, the DSCS II satellite carried only 2 communications transponders, compared to the 12 carried on INTELSAT IV, a commercial communications satellite of the same generation (127:108).

Third, unit costs for commercial systems have behaved like those for military space systems. The average cost of the INTELSAT commercial communications satellites (in constant 1983 dollars), for example, has gone from \$27 million for INTELSAT I in 1964 to \$82 million for INTELSAT IV-A in 1973, to \$178 million for INTELSAT VI in 1983 (127:61-4).

Comparing roughly equivalent generations of military and commercial communications satellites shows that the unit cost of the military satellites increased 226% between DSCS II and DSCS III, compared to 214% between INTELSAT IV and VI (127:64,80). Here again, "sticker price" comparisons do not include improvements in capacity and capability. Although total costs have increased, the price per circuit per month on INTELSATS has decreased dramatically, from \$5000 in 1965 to \$78 in 1983. As mentioned above, military communications satellites trade off significant communications capabilities in return for improved survivability against threats, so a comparison of communications capabilities vs. cost is only partially accurate.

Since military communications satellites must meet tactical and strategic needs beyond carrying long-distance communications, circuit month costs are not available, and would not provide a comprehensive basis for comparison in any

case. However, simply comparing the DSCS II and DSCS III satellites (excluding IDCSP satellites, which differed significantly in the service they provided), the ratio of unit cost to available channel-months has decreased from \$ 0.25 million per channel per month to \$ 0.19 million.

Comparisons of costs versus capability are even more difficult to derive for navigation, meteorological, and other military satellites. The example of the DSCS satellites does suggest, at least, that unit cost trends for military space systems do not differ significantly from those for commercial systems. In addition, the ratio of capability versus cost shows that while unit costs have increased, the cost of the services provided by the satellites has decreased--dramatically for commercial systems, less so for military systems.

Equity and Allocative Efficiency--Profits and Risk-Bearing. In more than one way, profit is the bottom line of an industry's performance. For defense industries, in the minds of the public, profit--high profit--is the best indication that producers are reaping "rewards far in excess of what is needed." This section looks at the profits earned in the spacecraft industry in light of "what is needed to call forth the amount of services supplied"--in particular, the financial risks assumed by contractors in producing a space system.

This discussion must begin with a caveat. No firm has ever reported its earnings from the sale of spacecraft. Only

one firm, TRW, even reports its total sales proceeds from spacecraft (143). The fact is that satellites are still a small part of any firm's business, too small to show up even in a line-of-business report. Therefore, this study must rely on assumptions and approximations.

The main assumption is that the profits from spacecraft production do not differ significantly from those earned in other lines of defense business. First, there are controls on the profits earned from defense contracts. The negotiated fee in cost-reimbursement contracts must keep net profits within the statutory limit. The Vinson-Trammel Act restricts the profit on sales earned on major systems contracts to 12% on production contracts over \$10,000, 15% on R & D contracts (146:280). The Renegotiation Board exists to investigate suspected cases of excess profits on defense contracts and reduce them to within the legal limit (146:6). The General Accounting Office also conducts audits of contracts to identify and bring pressure (but not to prosecute, since it is an advisory body) on cases of excess profit. Second, between 1976 and 1981, there were only 2 cases of defective pricing brought before the Renegotiation Board from Space Division (146:151). This suggests that profits on contracts with Space Division have not been observed to be excessive. Finally, there is a substantial body of analysis of the profitability of defense firms, none of which has conclusively established any tendency towards high profits (68:85-89). Indeed, the overwhelming evidence indicates that defense firms have earned profits less

than or equal to those in other commercial sectors (16:1103; 27:728; 86:290; 99:314; 138:692; 146:151,188).

Two approximations of return on investment will be used to assess the profitability of spacecraft manufacturers relative to other defense firms. The first is the price-cost margin, defined for Census data as (118:272):

$$\frac{VS - MC - PC}{VS}$$

where VS stands for the value of shipments, MC for the cost of materials, and PC for payroll cost. Although not a close approximation of profitability, since it does not include the cost of central office and other overhead functions, this index is used because it is readily available for a large number of industries through the Censuses of Manufacturers. The second is the ratio of operating profits to sales. This ratio has been said by some to be "largely useless for economic analysis" unless accompanied by capital investment figures, because it provides no measure of the investments required to generate revenues (101:9). There have been suggestions, however, that return on sales is a useful index in defense industries, where firms often tend to focus more on increasing the volume of sales than on return on investment, (68:84-5; 101:9). In addition, this is the index used in DOD contract negotiations.

The price-cost margins for the spacecraft industry (SIC 37612) for the only years reported, 1967 and 1982, are .304 and .166, respectively, suggesting a decrease in profitability (44; 47). In contrast, the figures for the

Table XIX.

Price-Cost Margins for Defense Industries, 1967-1982.

SIC	Industry	1967	1972	1977	1982
3761	Missiles, Space	.27	.29	.32	.33
3573	Computers	.29	.27	.33	.31
3721	Aircraft	.17	.22	.28	.16
3795	Tanks	.07	.21	.18	.23
3724	Aircraft Engines	(NA)	.18	.25	.27
3662	Comm. Equipment	.18	.24	.30	.30
3728	Aircraft Parts	(NA)	.27	.28	.28
3483	Ammunition	.15	.11	.29	.36
3731	Shipbuilding	.14	.14	.20	.24
	All Manufacturing	.23	.23	.23	.23

Sources: 44; 45; 46; 47; 49:746; and calculations by the author.

guided missiles industry (SIC 37611) for the same years show an increase, from .196 to .318. The trend in spacecraft also differs from that observed in other defense industries, all of which had consistent increases in their price-cost margins between 1967 and 1982 (see Table XIX). Moreover, the 1982 margin for spacecraft was lower than all other aerospace industries (SICs 372 and 376) except aircraft, which experienced a recession in the early 1980s (4:A25). This may indicate that the spacecraft industry is somewhat less profitable.

Profits-to-sales ratios, on the other hand, appear to be increasing in the missiles and space industry. A sample of profit-to-sales ratios in the SIC 3761 line of business between 1978 and 1984 for 6 firms (Boeing, General Dynamics, Lockheed, McDonnell-Douglas, Martin-Marietta, and Rockwell) revealed

annual profits per firm averaging 7.2% over the period (62). This was higher than the 4.7% average for defense contractors reported in the "Profit '76" study (144:188). The line of business profits also showed a slight increase in profits between 1978 and 1984 for all firms except McDonnell-Douglas, which suffered a loss of earnings in the first quarter of 1984 (5:30 Jan 85).

Looking in from the outside, then, it is difficult to clearly determine the profitability of the spacecraft industry. However, it may be possible to evaluate profits by looking at how investment risks have been shared between the federal government and the industry. The advanced technological requirements of space flight demand substantial investments in research and development. This implies risk and uncertainty about future profits, and in theory, would be reflected by high profits in the long run (75:36).

But the government provides the majority of funding for R & D in the aerospace industries, reducing the risk to the contractor. Between 1976 and 1981, the government provided an average of 75% of total R & D funds in the aerospace industries (SICs 372 and 376) (105:24). For most firms in the spacecraft industry, the company's share of R & D expenditures even less than the average of 25%. Between 1980 and 1984, internally-funded R & D averaged 16.2% for Rockwell, 14.5% for Lockheed, 14.3% for Ball, and 13.3% for TRW (22: 90; 116; 143). These funds tended to go to firms

with large market shares. In 1981, 62% of federal R & D expenditures in the aerospace industries went to the top 4 firms (Boeing, McDonnell-Douglas, Rockwell, and Lockheed), and this amount represented 32% of all federal R & D funds (106:24,32). Clearly, the government assumes the majority of the risk in aerospace R & D investment, which leads to the conclusion that if high profits are being made in the industry, they are not justified by any substantial investment in research.

The other aspect of industry risk-bearing is in capital investment. Figures on capital investment in spacecraft production are not available on an individual firm basis. There are some indications that capital investment in recent years has kept pace with that in the overall manufacturing sector. In 1982, new capital expenditures represented approximately 3.8% of the value of shipments for all manufacturing industries (49:746). For the same year, TRW's annual report stated that over \$19 million had been spent on improvements to space simulation and test facilities, against reported spacecraft sales of \$486 million (143). These expenditures alone represent a capital investment of 3.9% on sales. Rockwell has reported that it spent over \$50 million on production and test facility additions and improvements for the \$1.245 billion GPS production contract, an investment ratio of 4.0% on sales (56; 124). On the other hand, the ratio of new capital expenditures to the value of shipments reported for SIC 37612, Complete Space Vehicles, was less than 2.8% (47). The

available information on capital investment in this industry is not sufficient to determine which figures are most accurate, so no firm conclusions can be drawn.

Conclusion.

The whole discussion of the structure, conduct and performance of the spacecraft industry must be viewed in the light of a single truth: this is still a young industry. Given the structure of the acquisition process and the fewness of competent bidders, there are few opportunities for competition in numbers. The industry appears to be only beginning to consider the economics of production, having seen a steady decline in productivity, accompanied by an increase in the costs of materials and labor. Based on sketchy evidence, its profits do not seem to be excessive. Although most of the R & D funds are provided by the customer, there is some evidence that capital investment is within the range of the overall manufacturing sector. The most dramatic trend observed is the increase in the materials cost margin, which has reduced the price-cost margin to the lowest of all major defense industries. The rise in materials costs stems at least in part from the trend towards greater reliability, longer lifetimes, and higher unit costs of spacecraft, while production runs have remained small. As the next chapter describes, much of the structure, conduct, and performance of the spacecraft industry is due to these and other features of spacecraft as products and the demand for them.

V. Conclusion

This chapter distills from the preceding discussions the critical features of structure, conduct, and performance which contribute primarily to the character of competition in the defense spacecraft market and identifies the important links between these dimensions. It then compares these findings with the concept and criteria of effective competition, and concludes with a recommendation about the need for further studies.

Review of Critical Dimensions of the Market

Structure. The nature of the product and the extent of the market appear to have the greatest effect on the nature of competition in the spacecraft market. A satellite is subject to environmental conditions unknown on Earth--the hard vacuum of space, wide ranges in electromagnetic radiation, temperatures from near absolute zero to hundreds of degrees Centigrade, and stresses during launch 8 to 12 times the force of gravity on Earth. Moreover, it must survive these conditions in isolation. Meeting these conditions requires that every component, down to the nuts, bolts, and chips, be designed and tested to insure it will operate properly and not fail on orbit. The cost of launching a single spacecraft ranges from \$20 million to over \$200 million dollars--which means that no owner can afford to replace spacecraft frequently. As a consequence, assured performance over its operational lifetime is of utmost

concern, justifying considerable investments in quality assurance and testing for reliability. The result is that spacecraft are among the most expensive of all manufactured products, ranging from tens to several hundred million dollars apiece. And satellites are only one segment of a space system, which also requires launch facilities, ground stations to control the satellites and their payloads, and the equipment for using the payload. Only a few customers--primarily the DOD, NASA, and some commercial ventures--have been able to undertake space programs.

At the same time, the demand for spacecraft is low in terms of numbers of units (3). The annual launch rate between 1978 and 1983 averaged under 20 satellites. The production run for a typical military, civil, or commercial space programs is from 3 and 6 satellites. Only recently, in the GPS program, was an initial production contract awarded for over 10 satellites. Space programs can last well over 10 years from concept exploration to full operational deployment, and current satellites themselves have on-orbit lifetimes of from 3 to 10 years. This means that the opportunities for participation in the spacecraft market are few.

The conditions of supply are influenced by the nature of the product and the demand. The technical complexity of spacecraft is such that no one firm has shown the capability to develop and manufacture a satellite without relying on subcontractors for both individual parts and major subsystems.

A satellite is essentially a variety of black boxes and subsystems hanging on a structure that itself accounts for only 5% of the total weight (17:19). Raw materials, then, represent a very small share of the total cost of materials used in the industry--less than 2% in 1982 (47:28-29). And because production runs are small, the finished products that make up the majority of input materials are purchased in small quantities. The availability and price of these components are also influenced by the extensive testing requirements for space use and the existence of alternative markets, particularly for electronic equipment. The labor inputs are also costly, due to the need for technical skills. Scientists and engineers make up the majority of the work force, and production workers have consistently been paid the highest wages in all defense industries.

These conditions directly determine most of the remaining features of the industry's structure. The technological sophistication of satellites forces firms to employ considerable numbers of scientific and engineering personnel to design, develop, manufacture, and test these systems. The emphasis on reliability requires them to maintain extensive simulation, testing, and certification facilities. At the same time, the extent of the market is limited in terms of total number of units demanded. Thus, participation in the market comes with a high price of admission, and potential competitors face firms with firmly established shares in a limited market.

Within the industry, strategic groups have been characterized by their choice of markets and their choice of particular spacecraft technologies in which to specialize. The firms with the smallest market shares have focused on small NASA and DOD programs, lacking the financial resources to take on the risk of developing a large-scale system. The firms with an expertise in communications satellites, on the other hand, have been able to establish strong footholds in the emerging commercial market. The largest group of firms has concentrated on DOD and NASA programs in the area of space. Their substantial reliance on government contract work, combined with the perception that the "Big Three" comsat builders have locked up the commercial market for the present, creates a strong "follow-on" imperative for them to compete for new programs to maintain or expand their market shares. This is reflected in the competition for Strategic Defense Initiative (SDI) contracts among members of this group.

The high barriers to entry into the market, combined with the small total number of satellites produced in a year explain why the number of sellers is relatively small--less than 15. However, the distribution of sales among these firms appears highly concentrated. A number of factors contribute to high concentration--differences in the sizes of programs and of production and test facilities among firms, the fact that some firms tend to specialize more than others, and even good luck in early spacecraft competitions. Despite

high concentration, the evidence about performance suggests firms have not earned profits from space-related business substantially different from those in other defense sectors, which in turn have not been seen to differ significantly from those in commercial sectors.

The high cost of materials would act as a force stimulating upstream vertical integration were it not offset by the relatively small size of most orders for parts and other materials. Another factor limiting vertical integration is the fact that the suppliers are often other members of the industry. Every firm has had subcontracting relationships with almost every other member of the industry. This has encouraged teaming among firms on large system contract proposals.

Conduct. The DOD acquisition process is the predominant influence on the behavior of sellers in the market. The process is lengthy, and is subject to a variety of internal and external pressures that can and do introduce changes to requirements that in turn can raise costs and stretch out development schedules. The acquisition strategies available to DOD space program managers are fairly limited, and the opportunities for competition between sellers exist only in the early phases of a program. By the production stage, the DOD usually faces a single seller in its contract negotiations.

Improving technical performance is a primary goal of major systems acquisition programs, and to this end, the DOD

and NASA invest significant funds in research and development efforts. The government's share amounts to three-fourths of the total R & D investment in the aerospace industry. These R & D funds allow spacecraft manufacturers to maintain the technical and scientific base essential to competing in the market. Since R & D efforts precede most major systems programs, contractors have a strong incentive to get involved early. In addition, because cost is only one of the criteria by which the DOD selects the vendor for a major system, this price insensitivity is reflected by the relative insensitivity of firms to the price of input materials.

As mentioned above, the competition for the government space contracts reflects the different characters of the strategic groups in the industry. Firms obeying the "follow-on" imperative tend to compete on more programs, hoping to secure contracts that will keep their facilities at a steady or increasing level of work. The firms with small market shares have attempted to win larger contracts as a way of expanding into this group, but must be more selective, being less able to bear the costs of very many losing proposals. Firms active in the commercial market have been able to reduce their reliance on government space contracts. They tend to enter only those competitions where they have an upper hand, such as replacement programs for systems they currently build.

Performance. The structural features of the industry--

high concentration and high barriers to entry, should, in theory, be conducive to high profits. Instead, two factors appear to have reduced the profit margin in spacecraft manufacturing. The first is the fact that profits on sales to the two major customers--the DOD and NASA--are limited by the Vinson-Trammell Act. The second, and perhaps more significant, factor is the rise in the cost of materials since the mid-1960s.

It may be impossible to accurately estimate from the outside the profits earned in the spacecraft industry. Satellites are a small part of a firm's business, accounting for less than 10% of total sales for most industry members. Major system contracts with the DOD and NASA, which still represent the majority of industry sales, are limited to a profit rate of 12% of total costs on production contracts. Thus, profits in the spacecraft industry on DOD and NASA sales can be expected to fall within the range observed in numerous studies of defense firm profits. Here, the overwhelming evidence indicates profits on sales less than or equal to those earned in commercial sectors. As mentioned earlier, those incidences of high profits in this industry do not appear to be justified by investments in R & D at least, since the government provides the majority of these funds. The evidence on capital investment, reflected in the ratio of capital expenditures to sales, is mixed, but is within the range of other manufacturing industries.

The evidence on price-cost margins for SIC 37612.

Complete Space Vehicles, suggests that profits may even be less than those of other defense industries (47). This is partly due to increases in wages and benefits that have not been offset by comparable increase in worker productivity, resulting in higher labor costs per unit of output. The increase in materials costs, has exceeded the increase in the total cost of labor, thus reducing the profit margin. The cost of materials as a percentage of sales increased 80% between 1967 and 1982, resulting in a 45% decrease in the price-cost margin over the same period (44; 47). By 1982, this margin was less than that reported for all other defense industries except aircraft manufacturing.

The increase in the unit cost of materials stems, at least in part, from the conditions described earlier. As the weight, lifetime, and capabilities of satellites have increased, so has the number of subsystems and components. The understanding of the operational requirements of space has improved, resulting in more tighter specifications for suppliers to meet. The size of production runs has not increased significantly, however, while terrestrial applications of technologies like electronic miniaturization and solar power have. Without the advantage of economical order sizes and quantity discounts and with competition from alternate markets, prime contractors have little leverage in holding down the costs of materials. The use of multi-year procurements by the DOD may begin to improve the situation by allowing primes to place single large orders rather than a

number of small orders spaced over a few years.

Effective Competition in the Market

How do these observations about the market relate to the concept of effective competition? Effective competition embodies a recognition of the practical constraints on a market which keep it from ever fitting the model of perfect competition. The various structural, conduct, and performance criteria proposed for judging the behavior of a market are, in effect, a list of symptoms which, when evaluated together, allow a diagnosis of the conditions of competition in that market to be made. The aim of this diagnosis is to identify areas in which public policy might encourage changes that could improve the market's performance.

In the case of the defense spacecraft market, the dominant influences on the structure, conduct, and performance of the market are the nature of the product, the extent of the market, and the nature of the DOD as a buyer. Sosnick's approach of identifying those market conditions that are undesirable, avoidable, and verifiable in order to assess the need and opportunities for public policy changes seems most useful in this example (6:850).

In any defense market, the most obviously undesirable condition is one that fails to maintain national security. It is not adequate, however, to simply say that the continued effective operation of defense space systems implies the market is performing effectively. At the outset of this

study, it was suggested that defense markets should use each dollar of acquisition funds efficiently, since, in Garwin's words, "A dollar spent unnecessarily is a dollar of military capability denied us" (3:24). Sosnick lists several criteria related to lack of efficiency in a market: inefficient exchange, inefficient production, and inefficient rules of trading (6:842-850).

All three conditions can be observed in the defense spacecraft market. Inefficient exchange involves needlessly high costs of transactions. Comparing commercial and military communications satellite programs, it is apparent that commercial programs are able to obtain the same level of product performance without the minutely detailed specifications and contractual clauses of military programs (4:10-17). While the costs of this added documentation are buried in overhead accounting and cannot be evaluated, it does not appear to improve the quality of the product.

Inefficient production stems from the low numbers of units required by most programs, but is compounded by single-year procurements. The extent of the market to date has been such that little hard information about the economies of production runs has yet been obtained. The proponents of multi-year procurement suggest that there are opportunities for savings by allowing prime contractors place economical quantity orders with some suppliers. The first three multi-year procurements of satellites--DMSP, DSCS III, and GPS--are still underway, so any figures on savings are only estimates.

Although there is qualitative evidence that productivity improvements are being made in the industry, the quantitative evidence indicates these measures have not yet increased efficiencies. The bottom line is that the market for spacecraft is probably still too limited for there to be any clear understanding about internal efficiencies.

The last aspect of inefficiency, inefficient rules of trading, brings up questions about defense procurement that go well beyond the limits of the spacecraft market. The current approach to acquiring major defense systems is the product of more than one reform initiative, yet defects remain. The very recent phenomenon of teaming by industry members on proposals indicates that, on the sellers' side at least, there may be ways of reducing the cost of the acquisition process. As the discussion of conduct attempted to bring out, the acquisition process comprises management, contracting, planning, financial, operational, political, social, and other goals and measures. To try to analyze what combination of reforms would make the process in the spacecraft market more efficient is beyond the scope of this study.

Conclusion

What is the state of competition in the spacecraft market? Sosnick argues that a market is effectively competitive if, and only if, it has no verified undesirable and avoidable conditions (6:850). On this basis, the spacecraft market is not effectively competitive. There is room for improvement.

The significant erosion of the price-cost margin by the

increasing costs of materials is perhaps the most striking feature of the spacecraft market's performance. If performance is indeed what is of ultimate importance in a market, then this evidence suggests that further analysis of the nature of input costs in the market may be the most fruitful area of investigation for those interested in moving the market closer toward effective competition. Multi-year procurement may improve the prime contractor's leverage in controlling the price of materials, but this can only be studied once the current MYP contracts have been closed and the final accounting completed. Finally, the extent of networking among industry members in subcontracting relationships and the trend towards teaming on proposals are phenomena which deserve further investigation to better understand how they may affect the market's performance.

The spacecraft industry did not exist thirty years ago. It experienced explosive growth followed by a significant slump followed by the rise of a commercial market and a renaissance of the military market. It has produced some of the most awesome technical achievements of this era, and promises to bring about others in the future. As this study has tried to show, however, these achievements should not obscure the fact that the buyers and sellers are still attempting to understand the impact of economic realities of supply and demand, of efficiency and equity.

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